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TECHNICAL NOTE

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TRANSPORT AIRPLANES FROM 1947 TO 1958

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TRANSPORT AIRPLANES FROM 1947 TO 1958

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SUMMARY

Data obtained with VGH and V-G recorders from piston-engine airplanes used in feeder, short-haul, and long-haul transport operations during 1947 to 1958 have been analyzed and compared to determine the variations in the magnitude and frequency of occurrence of gust velocities, gust and maneuver accelerations, and the associated airspeeds. Estimates of the overall gust and gust-acceleration histories for extended operations were obtained in several cases by combining V-G and VGH data obtained from the same operation.

Maximum differences between the gust acceleration frequencies for the various operations are about 40 to 1 and are due primarily to differences in airplane wing loadings and, to a lesser extent, to differences in the gusts encountered and airspeeds flown in rough air. In general, operational maneuver accelerations are smaller and occur less frequently than gust accelerations. However, differences between frequencies of occurrence of check-flight maneuver accelerations for the various operations are as high as 100 to 1 and, for some operations, positive check-flight maneuver accelerations are as large and occur as frequently as gust accelerations. The number of gusts per mile of flight experienced during the various operations differ by a factor as high as 20, apparently because of differences in the amount and intensity of turbulence on the various routes, differences in turbulence-avoidance procedures, and differences in operating altitudes for the various operations. Significant reductions are noted in the frequency of occurrence of gust velocities with increasing altitude up to 20,000 feet. Operating speeds were not reduced when rough air was encountered during the climb and cruise conditions but, for some operations, small airspeed reductions were noted for the descent flight condition.

INTRODUCTION

As a continuation of NASA interest in collecting gust loads information on commercial transport airplanes, a systematic sampling program

for collecting normal-acceleration, airspeed, and altitude data during routine operations was begun in 1947. The primary purpose of this program was to determine the magnitude and frequency of occurrence of gust and maneuver accelerations, gust velocities, and the associated flight speeds and altitudes during operations of piston-engine airplanes of the type introduced after World War II. The data were obtained with the NASA (formerly NACA) VGH and V-G recorders installed in several types of piston-engine transport airplanes which were selected for the purpose of obtaining representative samples of feeder, short-haul, and long-haul airline operations. Most of the results obtained from the various operations have been published (refs. 1 to 16) as the individual samples of data became sufficient in size for analysis. Additional data also have been obtained from operations involving airplanes of later design than those reported in references 1 to 16, and the collection of V-G and VGH records is continuing from airplanes engaged in current operations.

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For the purpose of providing a convenient reference for the gust-loads information obtained from the V-G and VGH data in recent years, a single compilation of the major results obtained from the various operations appeared desirable. Accordingly, the present paper summarizes the data on the gust velocities, the gust and maneuver accelerations, and the operational airspeeds and altitudes for the operations sampled since 1947. The magnitude and frequency of the gust velocities and gust accelerations experienced in the various operations are indicated, and the gust accelerations are compared with the accelerations caused by operational and check-flight maneuvers. For the several operations in which both V-G and VGH data samples were provided, the two types of data have been used to derive estimates of the overall gust and gust-acceleration histories. The airspeed data are examined to determine the airspeed operating practices in smooth and rough air. The variation of gust intensity with altitude is also examined.

SYMBOLS

a_n	normal acceleration, g units
$a_{n,LLF}$	normal acceleration corresponding to the limit-gust-load-factor increment ($n - 1$), g units
A	aspect ratio, b^2/S
b	wing span, ft
c	mean geometric chord, ft

$\Sigma f()$	cumulative frequency of the pertinent variable
g	acceleration due to gravity, ft/sec ²
H	pressure altitude, ft
K_g	gust factor (ref. 1), $\frac{0.88\mu_g}{5.3 + \mu_g}$
l	flight miles represented in the sample of data
m	slope of the wing lift curve, $\frac{6A}{A + 2}$, per radian
n	limit-gust-load factor (computed according to ref. 17)
S	wing area, sq ft
U_{de}	derived gust velocity (ref. 1), $\frac{2a_n W}{\rho_o V_e m S K_g}$
V	true airspeed, ft/sec
V_B	design airspeed for maximum gust intensity (ref. 17, p. 12), mph
V_C	design cruising airspeed (ref. 17, p. 12), mph
V_D	design diving airspeed (ref. 17, p. 12), mph
V_e	equivalent airspeed, ft/sec
V_L	design maximum indicated airspeed in level flight (ref. 18), mph
V_{max}	maximum indicated airspeed, mph
V_{NE}	indicated never-exceed airspeed (ref. 17, p. 44), mph
V_O	indicated airspeed at which maximum positive or negative acceleration occurs on a V-G record, mph
V_p	most probable operating indicated airspeed at which maximum acceleration occurs in a sample of V-G data, mph

W	airplane weight, lb
μ_g	airplane mass ratio (ref. 1), $\frac{2W}{pcgms}$
ρ	mass density of air, slugs/cu ft
ρ_0	mass density of air at sea level, slugs/cu ft
σ	standard deviation for a distribution of values

A bar over a symbol indicates the average value of the variable for the given distribution of values.

Subscript:

max maximum value of the variable

INSTRUMENTATION AND SCOPE OF DATA

The data were collected with NASA VGH and V-G recorders, which are described in detail in references 19 and 20, respectively. The VGH recorder yields a time-history record of indicated airspeed, pressure altitude, and normal acceleration, from which detailed counts of the normal acceleration peaks of different intensities, along with measurements of the associated airspeeds and altitudes, can be obtained. The V-G recorder, on the other hand, records an envelope of the positive and negative accelerations against the indicated airspeeds. Consequently, only the maximum airspeeds and the maximum positive and negative accelerations experienced at any airspeed for the total time represented by the V-G record (usually 100 to 300 flight hours) can be obtained. The V-G data are used, therefore, primarily to obtain estimates of the large and relatively infrequent gust velocities, accelerations, and airspeeds, whereas the VGH data are used for more detailed studies of the gusts, accelerations, and the associated operating conditions of airspeed and altitude. The VGH and V-G data obtained from the same operation are supplementary and may be combined to derive estimates of the overall gust and acceleration histories for the operation.

The scope of the V-G and VGH data samples is summarized in table I according to airplane type, operation, and type of airline service. As shown in table I, the VGH data consist of 17 samples representing operations of nine types of piston-engine transport airplanes in feeder, short-haul, and long-haul airline service, and the V-G data consist of 23 samples representing operations of eight types of airplanes. Some

of the pertinent airplane characteristics which were used for evaluating the data are given in table II. The values given were obtained either from the Civil Aeronautics Administration, from the design manual of the airplane manufacturer, or from computations made in accordance with reference 17, as indicated in the table. It will be noted that the characteristics of airplanes E and F are identical except for the difference in gross weight.

The data were collected by various airlines (identified as airlines I to XVI) on a number of routes within the United States and on several transoceanic routes as itemized in table I. Operations are identified herein by a combination of the letter designation of the airplane and the Roman numeral designation of the airline. For example, operation A-I refers to the operating conditions shown in table I for airplane A and airline I. Examination of table I shows that samples of both V-G and VGH data were collected on seven operations. Samples of data for operations D-IV and J-VIII were obtained from airplanes equipped with airborne weather radar. The individual data samples generally covered at least one year of operation. The sizes of the VGH data samples vary from 267 flight hours to 2,231 flight hours; whereas the sizes of the V-G data samples are much larger and vary from about 3,000 flight hours to about 48,000 flight hours. Table I lists the references from which most of the data samples herein were obtained.

EVALUATION OF RECORDS

VGH Records

The VGH records were evaluated essentially in accordance with the methods used in reference 15 to obtain frequency distributions of gust and maneuver accelerations, airspeeds, and altitudes. The evaluation procedure consisted of reading the gust and maneuver accelerations by using the steady-flight position of the acceleration trace as a reference. Only the maximum values of acceleration were read for each deflection of the acceleration trace greater than given threshold values - generally $\pm 0.3g$ for gust accelerations and $\pm 0.1g$ for maneuver accelerations.

The accelerations were classed as gust or maneuver accelerations on the basis of the criteria described in reference 16. The gust accelerations, together with the simultaneous values of airspeed and altitude, were sorted according to the flight condition - climb, en route, or descent - during which they occurred. The maneuver accelerations were classed and sorted according to the purpose of the flight on which they occurred. Thus, maneuver accelerations which occurred during routine operational flights were classed as operational maneuvers and those which

occurred during airplane or pilot check flights were classed as check-flight maneuvers.

The evaluation of the records to obtain distributions of airspeed and altitude consisted simply of tabulating, according to flight condition, the indicated airspeed and pressure altitude for each one-minute interval of flight.

In general, the total available samples of VGH data for each operation (table I) were evaluated for gust accelerations, operational maneuver accelerations, check-flight-maneuver accelerations, airspeeds, and altitudes. The total available VGH record samples were not, in all instances, evaluated completely for operational maneuver accelerations, inasmuch as reasonably accurate estimates of the acceleration frequencies can be obtained from relatively small record samples (ref. 16).

Derived gust velocities were calculated from the associated values of gust acceleration, airspeed, and altitude, with the revised gust-load formula given in the symbol list. The values of gust factor K_g for use in the formula were based on the mass parameter of the airplane computed for the midpoint altitude of each 5,000-foot-altitude interval. Since detailed information on the operating weight at the time of gust encounter was not available in most cases, an assumed average operating weight of 0.85 design weight was used in determining the values of K_g and in computing the gust velocities. For three operations, however, the operators supplied information on the average operating weights and these values (0.80W for operation J-VI, 0.86W for J-VIII, and 0.73W for J-X) were used in computing the gust velocities.

V-G Records

The values read from each V-G record were the maximum positive and negative accelerations $a_{n,max}$, the airspeeds V_0 at which the maximum accelerations occurred, and the maximum indicated airspeed V_{max} . Accelerations which occurred at low speeds (below 120 to 160 miles per hour, depending upon the airplane type) were not read in order to exclude the effects of maneuver during take-off and approach and impact shocks during landing.

The maximum positive and negative gust velocities $U_{de,max}$ were computed for each record by using the acceleration values and the corresponding values of airspeed in the gust-velocity formula (ref. 1). The values of the gust factor K_g used for evaluating the gust velocities

from the V-G data were based on the estimated average operating altitudes and on an assumed average operating weight of 0.85 design weight.

RESULTS

Gust Accelerations

The frequency distributions of the gust accelerations obtained from the V-G and VGH records are given in table III for each of the operations. The positive and negative acceleration distributions for each data sample have been combined in the table inasmuch as the two distributions were essentially symmetrical. Included in the table are the flight hours and flight miles represented by each of the distributions.

In order to facilitate comparison of the gust-acceleration experience for the various operations, the VGH and V-G gust acceleration data given in table III are plotted in figure 1(a) and 1(b), respectively, in terms of the average frequency with which given values of acceleration per mile of flight would be exceeded. The ordinate values were obtained by progressively summing each distribution of table III (by starting with the frequency for the largest acceleration) and then dividing each sum by the number of flight miles represented in the sample. The seven samples of V-G acceleration data from airplane A were combined into one overall distribution to represent this type of airplane and this overall distribution is plotted in figure 1(b). The distribution of V-G acceleration data for operation A-I is also given in figure 1(b) for subsequent comparison with the VGH acceleration data for operation A-I from figure 1(a). The curves in figure 1 were faired to represent the trends of the distributions.

The average gust acceleration frequencies for the climb, the en route, and the descent flight conditions are shown in figure 2 for three operations. These results were plotted from breakdowns of the VGH data samples given in table III and are typical of similar results obtained for the other operations.

Estimates of the overall gust acceleration histories, which are given in figure 3, were plotted from the distributions of accelerations for those operations which supplied samples of both V-G and VGH data. The curves shown in the figure were faired to indicate the expected acceleration frequency for the entire range of measured accelerations. The faired curves take into account the tendency of the V-G data, because of the envelope nature of the record, to underestimate the frequency of the smaller accelerations. (See ref. 5.)

As shown in figure 3, the V-G and VGH data points for operation D-IV without radar do not appear to be as compatible as the V-G and VGH data obtained with radar. Since reference 8 was published, that part of the data for operation D-IV which came from this reference has been reexamined in greater detail, and it is now believed that the V-G records obtained before the installation of weather radar may have been amplified somewhat by structural vibrations although the magnitude of the amplifications is not known. The reliability of the V-G data for operation D-IV without radar is, therefore, open to some question. In this regard, however, it may be noted that the suspect V-G data appear to be in fair agreement with V-G data obtained from other short-haul operations without airborne weather radar using airplanes of similar type flown at approximately the same altitudes. (Operations C-V, C-IX, and C-XVI, figs. 1(b) and 6(b).)

The transport airplanes on which the data were collected were designed for different limit-gust-load factors, depending upon such characteristics as wing loading and airspeed, and consequently the acceleration distributions given in figure 3 do not provide a direct comparison of the relative severity of the gust-load experience in the different operations. In order to relate the accelerations to the airplane design values, therefore, the acceleration histories represented by the faired curves in figure 3 are replotted in figure 4 in terms of the average frequency with which given proportions of the limit-gust-load factor increment were exceeded per mile of flight. For this purpose, the measured accelerations a_n were divided by the acceleration $a_{n,LLF}$ corresponding to the computed limit-gust-load factor increment for each airplane ($n - 1$ where n is given in table II).

Maneuver Accelerations

The frequency distributions of the positive and negative operational and check-flight maneuver accelerations evaluated from the VGH records are presented in table IV, together with the flight hours and flight miles represented by each distribution. In addition, this table gives for each data sample the number of hours actually spent in check flights. The large amount of rough air experienced in operation A-I made it impractical to distinguish the operational maneuver accelerations from the gust accelerations on the VGH records and, consequently, operational maneuver data for this operation are not given in table IV.

For comparison purposes, the positive and negative distributions of accelerations from operational and check-flight maneuvers (table IV) are plotted in figure 5 for each operation in terms of the average frequency of occurrence of accelerations greater than given values. The maneuver and check-flight acceleration frequencies plotted in figure 5 are based on the flight miles given in table IV for each respective sample.

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Gust Velocities

The frequency distributions of the gust velocities derived from the VGH and V-G data are given in table V for each of the operations and, in addition, are plotted in figures 6(a) and 6(b), respectively, in terms of the average frequency of exceeding given values of gust velocity per mile of flight. For those operations which supplied both V-G and VGH data, estimates of the overall gust histories were obtained in a manner similar to that used for the acceleration data of figure 3, and the estimates are given in figure 7. The apparent drop-off in gust frequency at the low values of gust velocity (fig. 6(a)) is attributed to incomplete frequency counts near the reading threshold.

In order to obtain an estimate of the average variation of the gust frequency with altitude, the gust data from the various VGH data samples were sorted and combined into a single distribution for each 5,000-foot interval of pressure altitude. The gust-velocity distributions thus obtained are plotted in figure 8 together with the number of flight miles represented in each distribution.

Airspeeds

The airspeeds read from the VGH records at 1-minute intervals were used to obtain the overall distribution of indicated airspeeds for the climb, en route, and descent flight conditions and the airspeeds corresponding to the gust accelerations were used to obtain the distribution of airspeeds in rough air. As an illustration of the type of distributions obtained, the results for one operation are given in figure 9(a) as the fraction of the total time in each flight condition which was spent at given airspeeds. For comparison with the airspeed data, the design speed for maximum gust intensity V_B and the design cruising speed V_C are also indicated in the figure. In order to summarize similar results from the various operations, the average indicated airspeeds \bar{V} and the standard deviation of the airspeeds σ were obtained for each distribution and are given in table VI as fractions of the design cruising speed V_C . In addition to the results given for the three flight conditions, the table also gives the average airspeeds based on the total distribution of airspeeds for each operation. The data from table VI are plotted in figure 9(b) in order to facilitate comparison of the average airspeeds in smooth air with the average airspeeds in rough air ($a_n \leq 0.3g$).

In addition to the average airspeeds obtained from the VGH records, the airspeed data from the V-G records were used to determine the most probable speed V_p at which maximum acceleration would be experienced.

(See ref. 2.) For each operation the ratios of V_p to the design cruising speed V_C and the average flight miles to exceed the never-exceed speed V_{NE} are given in table VII. A comparison of V_p/V_C with the average speeds in rough air V_{rough}/V_C is given in figure 9(c) for the operations which supplied both V-G and VGH data.

For convenience in comparing the maximum airspeeds obtained in the different operations, Pearson Type III probability curves (see ref. 2) were used to describe the distribution of maximum airspeed V_{max} given in table VII. These curves are plotted in figure 10 in terms of the average flight miles required to exceed given fractions of the design never-exceed speed V_{NE} . Inasmuch as the analysis is concerned mainly with the high values of V_{max} , only the part of the curves for the larger values of airspeed are given in figure 10. Extrapolations of the data are indicated by the dashed portions of the curves.

Altitudes

The values of pressure altitude read from the VGH records were used to obtain the distributions of flight time spent at given altitudes during the climb, en route, and descent flight conditions. Inasmuch as the altitude distributions obtained for the operations in each type of service (i.e., feeder, short haul, or long haul) were similar, the distributions were combined according to the three types of service and are plotted in figure 11 to show the percentage of time spent above given altitudes in each flight condition. The average cruising altitudes for each operation are given in table I and the percent of total time spent in each flight condition is given in table VI.

RELIABILITY OF RESULTS

The reliability of the V-G and VGH results depends upon the instrument and installation errors, record-reading errors, and sampling errors attributable to the limited sizes of the available samples. The errors inherent in the instruments are discussed in detail in references 19 and 20. Record reading errors and sampling errors are discussed in detail in references 5 and 16. The major considerations pertinent to the reliability of the data presented are given in the following paragraphs.

The VGH installations met the basic installation requirements given in reference 19; consequently, the installation errors for the present

data are believed to be negligible. The estimated maximum instrument errors in the VGH data for each of the quantities measured are:

Acceleration, g units ± 0.05

Indicated airspeed, mph:

At 100 mph ± 5

At 300 mph ± 3

Pressure altitude, ft:

At 2,000 ft ± 150

At 20,000 ft ± 300

On the basis of laboratory calibrations of the V-G recorder (see ref. 20) the instrument errors are less than $\pm 0.1g$ for acceleration and about 1 percent of the full range of airspeed covered by the recorder.

Random errors which may have occurred in reading the V-G records are felt to have negligible effect on the V-G data. Errors in reading the VGH records, although estimated to be small, of the order of $0.05g$ (see ref. 8), can seriously affect the estimated number of accelerations exceeding given values. Experimental checks have indicated that for individual records the counts above $0.3g$ are only reliable to about ± 30 percent. Since the reading errors tend to balance out as the VGH data samples increase in size, it is estimated that the values for the cumulative frequency per mile given in figures 1(a) and 6(a) are accurate to within ± 20 percent.

There is no precise method available for determining the statistical reliability (that is, applicability to extended periods of operation) of the present results. Rough estimates of the reliability of the VGH data were obtained, however, by examining the variations in the data from groups of records forming the total samples. From such observations and past experience with results of the type presented, the total distributions of gust accelerations (figs. 1, 3, and 4) and gust velocities (figs. 6 and 7) are believed to be reliable within a factor of 3 on the ordinate scale at the smaller values and within a factor of 4 at the higher values. The reliability of the distributions by flight condition (fig. 2) is less, however, since these distributions represent smaller data samples. The maneuver acceleration frequencies given in figure 6 are estimated to be reliable within a factor of 4 over the range of the data.

No special operating limitations, with the exception of airspeed restrictions that were imposed in the case of operation B-II (see ref. 6), are known to have been in force when the present data were collected; therefore these data, as a whole, are considered to represent normal air-line operations. The effects of dynamic structural response on the

accelerations measured at the center of gravity of the airplanes used in the present investigation are in most instances unknown and are not accounted for in either the acceleration or gust-velocity data. As an indication of the magnitude of the dynamic effects, however, it may be noted that past flight test investigations (ref. 21) indicate amplifications of about 5 percent for airplane A and about 20 percent for airplane B.

DISCUSSION

Gust Accelerations

Inspection of the VGH and V-G acceleration data in figure 1 shows variations on the order of 40 to 1 in the frequencies of occurrence of given values of acceleration for different operations. Variations as high as 8 to 1 are evident between the acceleration frequencies for the same type of airplane operated on different routes (operations J-VI, J-VIII, and J-X in figure 1(a), for example). The variations noted in the acceleration histories in figure 1 are due, primarily, to differences in the airplane wing loading (see table II) and, to a lesser extent, to differences in the severity of the gusts experienced and the operating airspeeds in rough air.

The results shown in figure 4 indicate that although maximum variations on the order of 10 to 1 are apparent between different operations in the frequencies with which given proportions of the limit-gust-load factor increment $a_{n,LLF}$ would be exceeded, the variations were for the most part about 3 to 1. The relatively low acceleration increments for operations A-I and D-IV in figure 4 were apparently attributable to the use of airborne weather radar in the case of operation D-IV and to conservative operating practice in regard to severe weather avoidance in the case of operation A-I. (See ref. 4.) From the overall viewpoint, the results in figure 4 indicate that for most of these transports $a_{n,LLF}$ would be exceeded, on the average, in about 10^6 miles of flight.

Figure 2 indicates that for certain operations, variations on the order of 10 to 1 may be expected between the frequencies at which given values of acceleration would be exceeded during the climb, en route, and descent flight conditions. The results shown for the three operations are representative of similar results for the other operations and indicate, in general, that the greatest number of accelerations per mile of flight were experienced in the descent condition and the least number in the en route condition. The higher frequency of occurrence during the descent condition is due to the combined effects of increased gust frequency at low altitudes (fig. 8) and high indicated airspeeds during the

descent (table VI). Although generally less than 20 percent of the flight time was spent in descent (see table VI), a high percentage (40 to 75 percent) of the total number of accelerations $\geq \pm 0.3g$ for each operation occurred during this flight condition. A reduction in airspeed in rough air for this portion of flight could result, therefore, in a substantial reduction in the total number of accelerations experienced.

Maneuver Accelerations

Consideration of the operational maneuver data in figure 5 indicates that the positive and negative distributions are roughly symmetrical and that the maximum operational maneuver accelerations are generally about $\pm 0.6g$. A comparison of the data from the different operations indicates that variations on the order of 10 to 1 exist in the frequency of occurrence of given values of operational maneuver accelerations. The differences could not be correlated with such parameters as airplane weight or length of flight, and the differences are therefore believed to be due to factors such as type of operation, pilot technique, and airplane handling characteristics.

The check-flight-maneuver data in figure 5 indicate that for most of the operations, the positive accelerations tend to be larger and to occur more frequently than the negative accelerations. Variations on the order of 100 to 1 exist in the frequency of occurrence of given values of check-flight-maneuver accelerations for the different operations and are apparently due to differences between airline and pilot practice in regard to the type, severity, and frequency of maneuvers performed during the check flights.

Figure 5 shows that gust accelerations were generally larger and more frequent than maneuver accelerations. For several operations, however, positive accelerations caused by check-flight maneuver were as large as, and occurred as frequently as, accelerations caused by gusts. From consideration of the overall results, therefore, maneuver accelerations can contribute substantially to the total loads histories of transport airplanes.

Gust Velocities

Consideration of the gust-velocity distributions in figure 6 indicates that large differences exist between the frequency of occurrence of given values of gust velocity for the various operations. Variations on the order of 10 to 1 are noted in the gust frequencies for the range of gust velocities represented by the VGH data (fig. 6(a)), and the largest differences evident in the gust frequencies for the larger gust

velocities (fig. 6(b)) covered by the V-G data do not exceed about 20 to 1. Similar variations exist in the gust frequencies for given airplane types operated on different routes (airplane H in fig. 6(a) and airplane G in fig. 6(b), for example). These differences apparently resulted from a combination of several factors, such as actual differences in the amount and intensity of turbulence on the various routes, differences in operating practices in regard to turbulence avoidance, and to differences in operating altitudes for the various operations.

Comparison of the estimated overall gust histories in figure 7 (combined V-G and VGH data) indicates variations of only about 5 to 1 for gust velocities larger than 20 feet per second if the results for operation A-I are discounted. The low gust frequencies for operation A-I apparently resulted from the effective avoidance of severe turbulence as was previously noted. The gust histories in figure 7 appear to be closely related in order of severity to the order for the gust-load histories of figure 4. For example, the two operations which have the lowest gust frequencies (operations A-I and D-IV) also have the lowest gust-load frequencies.

Figure 8 indicates significant reductions in the frequency of occurrence of given values of gust velocity with an increase in altitude up to 20,000 feet. The results indicate a somewhat higher gust frequency for altitudes from 20,000 to 25,000 feet than for altitudes from 15,000 to 20,000 feet. This apparent reversal in the trend of the data may not be significant, however, and may be due in part to an attempt to fly above the more severe turbulence conditions at the lower operating altitudes. In addition, the reliability of the VGH data may be somewhat less for altitudes from 20,000 to 25,000 feet than for the lower altitudes because of the smaller amount of time spent above 20,000 feet.

Airspeeds

The airspeed ratios \bar{V}/V_C given in table VI indicate that the average overall airspeeds in each flight condition (climb, en route, and descent) were substantially lower than the design cruising speed V_C . The average speeds range from about $0.5V_C$ to $0.9V_C$ and, in general, the airspeeds were lowest during the climb and highest during descent.

Comparison of the speeds in rough air with the overall speeds (see table VI and fig. 9(b)) indicates that the airspeeds were not reduced upon encountering rough air ($a_n \geq \pm 0.3g$) during the climb and en route conditions, but some small reductions in speed were made during descent in several operations, particularly those involving the operations of

the type J airplane. Inasmuch as the average speeds during climb for most of these operations were about equal to the design speed for maximum gust intensity V_B (see, for example, fig. 9(a)), no change in airspeed was necessary upon encountering rough air. The absence of significant airspeed reductions in rough air for the en route and descent conditions may be due to inability of the pilot to anticipate the turbulence soon enough to reduce airspeed or to a practice among pilots of not reducing airspeed except for very severe turbulence. In this regard, figure 9(c) indicates that the most probable speed for the occurrence of maximum acceleration for three operations was about equal to the average speed in rough air and was 5 to 10 percent lower for other operations. It appears, therefore, that airspeeds were reduced when severe turbulence was encountered for some operations but not for others.

The results presented in figure 10 indicate that the estimated number of flight miles to exceed the design never-exceed speed vary by several orders of magnitude between the different operations. The results suggest that the probability of exceeding V_{NE} is extremely remote for airplanes A and B. For the other airplanes, the estimated flight miles to exceed V_{NE} range from approximately 10^5 flight miles to 10^8 flight miles with an average value on the order of 5×10^6 flight miles. The results in figure 10 indicate that if the extrapolated results for airplane A are excluded, there are no appreciable differences between the frequencies with which the two-engine and four-engine airplanes would exceed V_{NE} . In regard to the high speeds recorded on the various airplanes, it may be mentioned that the high speeds were generally attained while the airplanes were flying in relatively smooth air.

Altitudes

The average cruising pressure altitudes for the various operations sampled ranged from about 5,500 feet to 19,000 feet (table I), although some of the long-haul airplanes occasionally operated as high as 25,000 feet. The altitude data shown in figure 11 define the pattern in operating altitudes for the three types of operations represented by the present data. The differences between the climb and descent pressure-altitude distributions for the feeder operation and the other operations may be attributed to the considerably higher terrain and airport elevations for operation A-I than for the short-haul and long-haul operations. It is also indicated in figure 11 that most piston-engine long-haul operations only occasionally exceeded pressure altitudes of about 20,000 feet. For operations involving airplane J, however, which had the highest cruising altitudes, more than 30 percent of the cruise time was spent above 20,000 feet.

CONCLUSIONS

An analysis of V-G and VGH data obtained during 1947 to 1958 from feeder, short-haul, and long-haul transport operations has indicated the following results:

1. Maximum variations between the acceleration frequencies for the various operations were about 40 to 1 but, in general, most of the acceleration frequencies varied by not more than 10 to 1 and were due primarily to differences in airplane wing loadings and to a lesser extent to differences in gusts encountered and airspeeds flown in rough air.

2. Variations in the frequency of occurrence of given fractions of the limit-gust-load factor increment for the different operations generally were less than about 5 to 1. The gust loads appear to be closely related in their order of severity to the gust velocities for the various operations.

3. The operational maneuver accelerations are smaller and occur less frequently than the gust accelerations. Variations in the frequency of occurrence of check-flight maneuver accelerations for the various operations were as high as 100 to 1 and, for some operations, positive check-flight maneuver accelerations were as large and occurred as frequently as gust accelerations.

4. The number of gusts per mile of flight experienced in the various operations differed by a factor as high as 20, apparently because of differences in the amount and intensity of turbulence on the various routes, differences in turbulence-avoidance procedures, and differences in operating altitudes for the various operations.

5. Significant reductions were noted in the frequency of occurrence of gust velocities with increasing altitude up to 20,000 feet.

6. In general the airspeeds were not reduced when rough air was encountered during the climb and cruise conditions but, for some operations, small airspeed reductions were noted for the descent flight condition.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., April 24, 1959.

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TABLE I.- SCOPE OF VGH AND V-G DATA FOR OPERATIONS FROM 1947 TO 1958

VGH Data

Airplane	Airline	Service	Routes flown	Dates of operation	Number of airplanes	Records analyzed		Average operating conditions				Ref.
						Total sample hours	Equivalent flight miles	Length of flight, hr	Pressure altitude (cruise), ft	Indicated airspeed		
										mph	knots	
A	I	a	Billings, Mont. - El Paso, Tex.	Feb. 1953 to Aug. 1954	1	1,278	2.1×10^5	0.63	9,600	146	127	4
B	II	b	Northern transcontinental	Apr. 1949 to Dec. 1949	1	834	1.8	0.93	5,500	203	176	5
C	III	b	New York - Los Angeles	Apr. 1950 to Apr. 1952	1	676	1.8	0.84	7,000	200	174	7
D	IV	b	New York - San Francisco - Seattle	Oct. 1955 to Apr. 1956	1	267	0.6	0.86	8,900	198	172	8
² D	IV	b	New York - San Francisco - Seattle	Apr. 1956 to Apr. 1958	1	693	1.5	0.85	8,900	192	167	
D	V	b	Chicago - Los Angeles - Seattle	July 1955 to Oct. 1956	1	1,458	3.3	0.83	11,200	195	169	--
F	VI	c	New York - Miami	Aug. 1951 to Aug. 1953	1	1,038	2.7	1.75	12,000	225	195	10
G	VII	b	Northwest U.S. - Alaska	Apr. 1956 to Mar. 1957	1	673	1.4	2.56	9,500	187	162	12
H	III	c	Southern transcontinental	Jan. 1950 to Oct. 1953	1	834	2.3	1.95	14,100	228	198	14
H	IV	c	New York - San Francisco	Nov. 1951 to Aug. 1953	1	1,062	2.8	2.15	14,900	217	188	
H	VIII	c	New York - Miami	Aug. 1953 to Nov. 1955	1	1,721	4.5	1.86	14,300	218	189	--
J	VI	c	New York - Miami - Caribbean	Oct. 1955 to Sept. 1957	1	1,158	3.5	2.50	17,300	242	210	--
² J	VIII	c	New York - Miami - Caribbean	June 1956 to July 1958	2	1,277	4.1	2.54	19,000	245	213	--
J	X	c	Chicago - New Orleans - South America	Oct. 1955 to Oct. 1956	2	2,231	6.7	1.78	17,400	250	217	--
K	II	c	Northern transcontinental	Feb. 1950 to May 1952	1	876	2.4	2.10	15,700	217	188	15
K	IV	c	Los Angeles - Honolulu - San Francisco	Nov. 1951 to Dec. 1953	1	1,953	4.9	7.86	13,100	207	180	
K	IX	c	Northern transatlantic and South America	Mar. 1952 to Sept. 1953	1	1,079	2.8	4.71	14,000	214	186	

¹Service:

- a - Feeder
- b - Short-haul
- c - Long-haul

²Equipped with airborne weather radar.

TABLE I.- SCOPE OF VGH AND V-G DATA FOR OPERATIONS FROM 1947 TO 1958 - Concluded

V-G Data

Airplane	Airline	Service	Routes flown	Dates of operation	Number of airplanes	Records analyzed				Ref.
						Number of records	Total sample hours	Equivalent flight miles	Average hours per record	
A	I	a	Billings, Mont. - El Paso, Tex.	Mar. 1953 to Oct. 1954	5	58	11,276	1.9×10^6	194	2
A	IV	b	New York - Los Angeles - Seattle	Apr. 1947 to Oct. 1949	2	10	9,829	1.7	983	
A	XI	b	Chicago - New Orleans	Apr. 1950 to Apr. 1953	3	30	10,409	1.8	347	
A	XII	a	Cincinnati - Norfolk - Myrtle Beach	Jan. 1953 to Feb. 1955	5	78	23,239	3.9	298	
A	XIII	a	Milwaukee - Wichita - Nashville	Oct. 1953 to Apr. 1955	3	19	7,534	1.3	397	
A	XIV	a	New Orleans - Memphis - Jacksonville - Charlotte	July 1953 to Apr. 1955	2	7	4,862	0.8	695	
A	XV	a	New Orleans - Kansas City - Minot, N. D.	Oct. 1948 to Feb. 1950	7	79	23,940	4.1	303	3
B	II	b	Northern transcontinental	Dec. 1948 to Apr. 1950	24	388	38,578	8.0	99	6
C	V	b	Chicago - Los Angeles - Seattle	July 1950 to July 1952	2	15	3,448	0.8	230	7
C	IX	b	Miami - New Orleans - South America	Apr. 1948 to Mar. 1953	3	34	4,273	1.0	126	--
C	XVI	a	New York - Boston - Montreal	Apr. 1953 to Apr. 1954	2	13	3,494	0.8	269	--
D	IV	b	New York - San Francisco - Seattle	Oct. 1955 to Apr. 1956	3	18	2,717	0.7	151	8
² D	IV	b	New York - San Francisco - Seattle	Apr. 1956 to Apr. 1958	3	58	10,610	2.8	183	
E	VI	c	New York - Miami - Caribbean	Nov. 1947 to Feb. 1950	10	194	48,187	12.0	248	9
G	II	c	New York - Seattle - Honolulu - Tokyo - Manila	May 1949 to June 1953	3	40	12,780	2.6	320	11
G	IV	c	New York - San Francisco - Honolulu	Aug. 1950 to Aug. 1953	4	42	7,057	1.4	168	
G	IX	c	Miami - Caribbean - South America	Nov. 1947 to June 1950	4	57	15,327	3.1	269	
G	IX	c	San Francisco - Australia - Orient	Mar. 1947 to Jan. 1950	10	117	27,288	5.5	233	
G	XI	c	Chicago - New Orleans - Caracas	June 1948 to Nov. 1950	3	20	7,305	1.5	365	
H	IV	c	New York - Los Angeles - Honolulu	Nov. 1949 to Apr. 1952	5	74	14,953	3.6	202	13
H	VIII	c	New York - Detroit - Miami - Havana	Sept. 1950 to Jan. 1953	4	58	16,546	4.0	285	
H	IX	c	Miami - Caribbean - South America	July 1949 to June 1951	2	37	6,602	1.5	178	
K	II	c	Northern transcontinental	Jan. 1951 to July 1953	4	166	15,387	4.1	93	15

¹Service:

- a - Feeder
- b - Short-haul
- c - Long-haul

²Equipped with airborne weather radar.

TABLE II.- AIRPLANE CHARACTERISTICS

Airplane	Number of engines	Gross weight, W, lb	Wing area, S, sq ft	Mean geometric chord, c, ft	Aspect ratio, A	Lift-curve slope per radian, computed from $\frac{6A}{A+2}$	Limit gust load factor, n	Design speed for maximum gust intensity, V _B , mph	Design cruising speed, V _C , mph	Design diving speed, V _D , mph	Never-exceed speed, V _{NE} , mph
A	2	25,200	987	10.4	9.1	4.92	3.34	138	^a 211	286	257
B	2	39,900	864	9.3	10.1	5.00	2.89	184	^a 256	325	292
C	2	40,500	817	8.9	10.3	5.03	2.76	175	280	350	315
D	2	47,000	920	8.7	12.0	5.14	3.03	185	^a 325	406	338
E	4	94,000	1,650	13.4	9.2	4.93	2.48	187	^a 271	360	324
F	4	107,000	1,650	13.4	9.2	4.93	2.31	187	^a 271	360	324
G	4	70,700	1,461	12.5	9.4	4.95	2.42	166	^a 222	295	266
H	4	89,900	1,463	12.5	9.4	4.95	2.54	183	300	399	360
^b H	4	93,200	1,463	12.5	9.4	4.95	2.47	187	300	399	360
J	4	122,000	1,463	12.5	9.4	4.95	2.18	207	310	399	360
K	4	147,000	1,720	12.2	11.7	5.12	2.18	202	312	389	350

^aValue used by manufacturer for design level speed V_L as specified in Civil Air Regulations O4a (ref. 18).^bCharacteristics for operation H-IV (VGH data only).

TABLE IV.- FREQUENCY DISTRIBUTIONS OF MANEUVER ACCELERATIONS FROM VGH RECORDS

(a) Operational maneuvers

Acceleration, a_n , g units	Frequency distribution for operation -														
	B-II	C-III	D-IV	D-V	F-VI	G-VII	H-III	H-IV	H-VIII	J-VI	J-VIII	J-X	K-II	K-IV	K-IX
1.1 to 1.2	-----	1	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
1.0 to 1.1	-----	1	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
.9 to 1.0	-----	0	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
.8 to .9	-----	0	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
.7 to .8	1	1	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
.6 to .7	0	0	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
.5 to .6	0	3	2	1	3	3	2	2	7	13	17	9	2	-----	-----
.4 to .5	16	19	12	16	10	7	4	18	16	12	36	57	6	1	1
.3 to .4	98	137	130	125	60	33	47	89	77	116	103	236	27	7	24
.2 to .3	822	1,154	855	980	241	327	465	636	649	643	633	1,600	295	88	144
.1 to .2	5,145	10,748	14,428	17,434	4,167	5,859	2,817	3,962	13,888	9,815	9,711	20,520	1,534	770	1,473
-0.1 to -0.2	5,227	8,041	13,069	16,061	3,560	6,770	3,164	5,022	13,089	8,059	8,055	18,794	1,449	1,220	2,248
-.2 to -.3	962	469	567	851	182	328	297	733	570	332	256	878	262	86	180
-.3 to -.4	112	54	75	111	18	11	25	98	65	30	21	90	27	11	18
-.4 to -.5	6	3	5	6	3	1	3	11	9	4	2	12	2	-----	1
-.5 to -.6	4	2	1	1	-----	-----	1	5	5	1	-----	3	-----	-----	-----
-.6 to -.7	-----	-----	-----	-----	-----	-----	-----	-----	3	0	-----	-----	-----	-----	-----
-.7 to -.8	-----	-----	-----	-----	-----	-----	-----	-----	3	1	-----	-----	-----	-----	-----
Total	12,393	20,633	29,144	35,586	8,244	13,339	6,825	10,577	28,386	19,030	18,837	42,201	3,604	2,183	4,089
Flight hours	837	804	961	1,458	375	673	834	1,036	1,722	1,158	1,277	2,231	303	309	307
Flight miles, μ	1.9×10^5	1.7×10^5	2.1×10^5	3.3×10^5	1.0×10^5	1.4×10^5	2.3×10^5	2.7×10^5	4.5×10^5	3.5×10^5	4.1×10^5	6.7×10^5	0.8×10^5	0.7×10^5	0.8×10^5

(b) Check-flight maneuvers

Acceleration, a_n , g units	Frequency distribution for operation -															
	A-I	B-II	C-III	D-IV	D-V	F-VI	G-VII	H-III	H-IV	H-VIII	J-VI	J-VIII	J-X	K-II	K-IV	K-IX
1.4 to 1.5	-----	--	---	-----	---	--	---	---	1	-----	---	-----	-----	---	---	---
1.3 to 1.4	-----	--	---	-----	---	--	---	---	0	-----	---	-----	-----	---	---	---
1.2 to 1.3	1	--	---	-----	---	--	---	---	1	-----	---	-----	-----	---	---	---
1.1 to 1.2	0	--	---	-----	---	--	---	---	1	-----	---	-----	-----	---	---	---
1.0 to 1.1	2	--	1	-----	---	--	---	---	1	-----	---	1	-----	2	---	---
.9 to 1.0	5	--	0	-----	---	--	---	---	1	-----	---	0	1	2	---	---
.8 to .9	7	--	8	-----	---	1	---	2	3	1	---	0	0	11	---	---
.7 to .8	8	2	5	-----	---	1	---	1	3	1	0	---	3	1	9	---
.6 to .7	20	0	17	1	---	2	---	7	3	1	---	---	6	1	20	---
.5 to .6	16	4	12	8	---	2	---	4	6	2	---	---	32	10	25	1
.4 to .5	39	12	38	27	1	6	2	13	37	4	12	36	20	39	4	---
.3 to .4	142	19	37	73	7	14	12	22	54	22	56	67	46	44	15	3
.2 to .3	468	---	---	271	19	---	54	180	323	212	110	200	155	---	38	20
.1 to .2	612	---	---	1,650	108	---	244	161	865	1,164	318	1,048	643	---	120	74
-0.1 to -0.2	674	---	---	1,460	90	---	282	200	757	1,092	259	922	524	---	77	48
-.2 to -.3	444	---	---	198	19	---	83	112	282	204	45	77	107	---	12	5
-.3 to -.4	130	6	30	46	4	8	11	10	33	30	12	18	20	8	1	---
-.4 to -.5	35	5	13	12	1	2	4	4	25	3	3	8	4	4	---	---
-.5 to -.6	9	2	2	0	---	1	---	2	7	---	1	4	---	2	---	---
-.6 to -.7	7	---	0	1	---	2	---	2	3	---	---	3	---	2	---	---
-.7 to -.8	1	---	1	-----	---	---	---	---	1	---	---	3	---	---	---	---
-.8 to -.9	3	---	---	-----	---	---	---	---	2	---	---	1	-----	---	---	---
Total	2,623	50	164	3,747	249	38	692	720	2,407	2,735	816	2,429	1,532	168	268	150
Flight hours	1,291	1,090	684	990	1,459	648	676	839	1,080	1,743	1,163	1,297	2,244	1,013	1,959	1,080
Flight miles, 1	2.2x10 ⁵	2.4x10 ⁵	1.5x10 ⁵	2.2x10 ⁵	3.3x10 ⁵	1.7x10 ⁵	1.4x10 ⁵	2.3x10 ⁵	2.8x10 ⁵	4.6x10 ⁵	3.5x10 ⁵	4.2x10 ⁵	6.7x10 ⁵	2.7x10 ⁵	4.9x10 ⁵	2.8x10 ⁵
Time in check flights, hours	12.8	4.7	8.4	29.1	1.3	12.3	3.1	5.2	18.5	21.3	5.0	20.3	13.1	7.5	5.2	1.3

TABLE V. - FREQUENCY DISTRIBUTIONS OF GUST VELOCITIES

(a) VGR data

Gust velocity, kt/gs, fps	Frequency distribution for operation -														K-IX
	A-I	B-II	C-III	D-IV	D-V	F-VI	G-VII	H-III	H-IV	H-VIII	J-VI	J-VIII (a)	J-X	K-II	
4 to 8	1,019	---	---	---	12	---	---	---	---	---	53	9	1,896	---	---
8 to 12	40,558	---	---	---	14,453	132	---	---	---	---	9,153	3,993	22,693	---	---
12 to 16	5,512	137	1,992	992	3,926	1,991	502	399	107	480	4,156	3,652	8,816	422	---
16 to 20	796	324	2,705	1,350	11,049	741	1,098	679	1,098	1,455	1,005	1,031	1,875	316	74
20 to 24	182	139	665	358	1,408	594	547	280	593	358	280	106	515	171	348
24 to 28	27	44	201	57	51	79	72	46	295	106	76	34	179	21	36
28 to 32	8	36	58	11	10	22	5	15	34	52	10	12	24	14	21
32 to 36	2	11	7	1	4	12	4	7	16	12	10	13	24	5	4
36 to 40	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
40 to 44	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
44 to 48	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
48 to 52	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
52 to 56	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Total	48,064	679	5,592	2,777	8,079	27,890	2,014	1,421	2,205	5,657	14,761	9,067	36,100	909	612
Flight hours	1,278	834	677	267	693	1,458	673	834	1,062	1,721	1,158	1,277	2,231	876	1,079
Flight miles, 1	1.8x10 ⁶	1.8x10 ⁶	1.5x10 ⁶	0.6x10 ⁶	1.5x10 ⁶	3.7x10 ⁶	2.7x10 ⁶	2.3x10 ⁶	2.8x10 ⁶	4.5x10 ⁶	3.5x10 ⁶	4.1x10 ⁶	6.7x10 ⁶	2.4x10 ⁶	2.8x10 ⁶

(b) V-G data

Gust velocity, kt/gs, fps	Frequency distribution for operation -																	
	A-I	A-IV	A-XI	A-XII	A-XIII	A-XIV	A-IV	B-II	C-V	C-IX	C-XVI	D-IV	D-IV (a)	E-VI	G-II	G-IV	G-IX	G-XI
12 to 16	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
16 to 20	6	1	12	1	7	3	---	---	---	---	---	---	---	---	---	---	---	---
20 to 24	23	4	38	33	5	1	---	---	---	---	---	---	---	---	---	---	---	---
24 to 28	28	6	33	30	6	3	---	---	---	---	---	---	---	---	---	---	---	---
28 to 32	18	3	23	23	2	2	---	---	---	---	---	---	---	---	---	---	---	---
32 to 36	9	2	12	12	3	2	---	---	---	---	---	---	---	---	---	---	---	---
36 to 40	5	1	6	6	5	5	---	---	---	---	---	---	---	---	---	---	---	---
40 to 44	1	1	1	1	1	1	---	---	---	---	---	---	---	---	---	---	---	---
44 to 48	1	1	1	1	1	1	---	---	---	---	---	---	---	---	---	---	---	---
48 to 52	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
52 to 56	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
56 to 60	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
60 to 64	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
64 to 68	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
68 to 72	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
72 to 76	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
76 to 80	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
80 to 84	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
84 to 88	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
88 to 92	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Total	116	20	60	156	38	14	158	776	30	68	26	36	116	368	80	84	114	40
Flight hours	11,276	9,829	10,409	23,239	7,534	4,862	23,940	38,578	3,448	4,273	3,494	2,717	10,610	48,187	12,780	7,057	15,327	27,888
Flight miles, 1	1.9x10 ⁶	1.7x10 ⁶	1.8x10 ⁶	3.9x10 ⁶	1.3x10 ⁶	0.8x10 ⁶	4.1x10 ⁶	8.0x10 ⁶	0.8x10 ⁶	1.0x10 ⁶	0.8x10 ⁶	0.7x10 ⁶	2.8x10 ⁶	12.0x10 ⁶	2.6x10 ⁶	1.4x10 ⁶	3.1x10 ⁶	5.5x10 ⁶

*Equipped with airborne weather radar.
Hydra-Pacific operation.

TABLE VI.- OPERATING AIRSPEEDS FOR VARIOUS FLIGHT CONDITIONS FROM VGH DATA

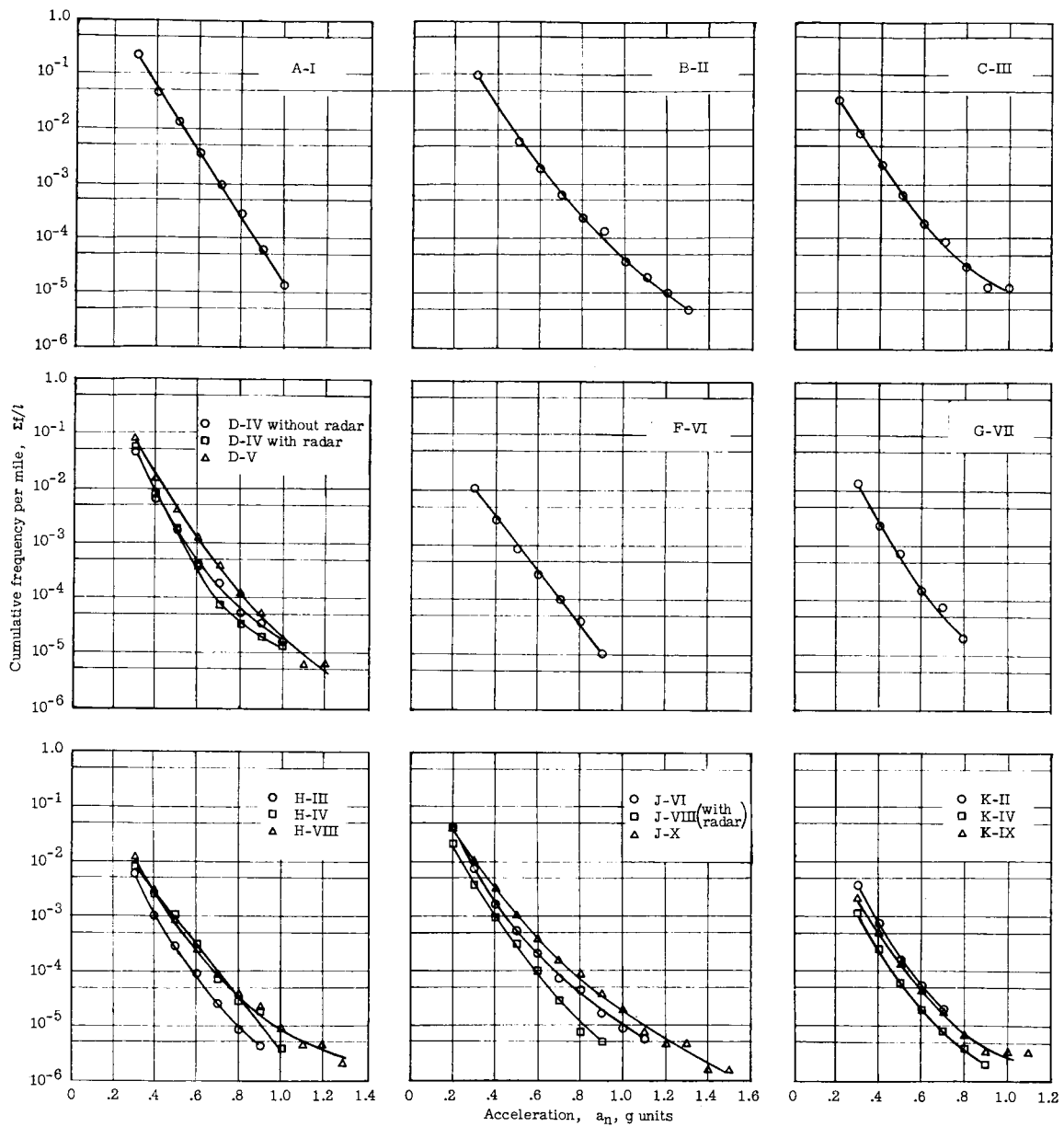
Operation	\bar{V}/V_C and σ for -										Percent of time in -		
	Climb			En route			Descent			Total			Descent
	Overall	Rough air		Overall	Rough air		Overall	Rough air		Overall	Rough air		
A-I	0.60 ± 0.05	0.62 ± 0.08		0.72 ± 0.06	0.72 ± 0.06		0.72 ± 0.09	0.73 ± 0.08		0.69 ± 0.09	0.71 ± 0.08		44.4
B-II	.65 ± .07	.65 ± .05		.82 ± .06	.79 ± .06		.77 ± .14	.74 ± .10		.79 ± .10	.76 ± .09		63.1
C-III	.61 ± .07	.64 ± .10		.74 ± .07	.73 ± .08		.71 ± .13	.72 ± .12		.71 ± .10	.71 ± .10		61.1
D-IV	.52 ± .05	.51 ± .05		.63 ± .05	.62 ± .06		.61 ± .12	.57 ± .12		.61 ± .08	.56 ± .10		62.6
^a D-IV	.51 ± .05	.50 ± .06		.61 ± .03	.60 ± .04		.60 ± .11	.56 ± .12		.59 ± .08	.56 ± .09		57.6
D-V	.52 ± .04	.52 ± .05		.61 ± .04	.61 ± .04		.64 ± .11	.62 ± .11		.60 ± .08	.59 ± .09		56.2
F-VI	.67 ± .08	.69 ± .10		.85 ± .06	.86 ± .07		.89 ± .16	.88 ± .13		.83 ± .12	.85 ± .12		66.8
G-VII	.71 ± .09	.72 ± .10		.85 ± .09	.86 ± .09		.87 ± .13	.86 ± .13		.84 ± .11	.85 ± .11		72.9
H-III	.64 ± .07	.66 ± .07		.77 ± .07	.77 ± .09		.80 ± .14	.80 ± .14		.76 ± .10	.78 ± .12		68.8
H-IV	.60 ± .08	.64 ± .11		.74 ± .07	.73 ± .08		.73 ± .15	.74 ± .13		.72 ± .11	.72 ± .12		67.3
H-VIII	.61 ± .08	.65 ± .09		.73 ± .07	.74 ± .08		.77 ± .14	.77 ± .09		.73 ± .10	.75 ± .11		67.5
J-VI	.66 ± .07	.65 ± .10		.79 ± .06	.79 ± .08		.85 ± .14	.78 ± .16		.78 ± .10	.76 ± .13		67.2
^a J-VIII	.68 ± .07	.67 ± .07		.79 ± .06	.80 ± .08		.85 ± .14	.77 ± .14		.79 ± .09	.76 ± .12		67.9
J-X	.66 ± .06	.66 ± .09		.80 ± .06	.80 ± .08		.85 ± .15	.80 ± .16		.79 ± .11	.77 ± .14		59.9
K-II	.61 ± .05	.65 ± .08		.70 ± .06	.68 ± .06		.77 ± .13	.77 ± .12		.70 ± .09	.74 ± .12		68.6
K-IV	.62 ± .04	.62 ± .07		.66 ± .04	.68 ± .06		.71 ± .11	.68 ± .11		.66 ± .05	.67 ± .09		89.7
K-IX	.66 ± .04	.65 ± .05		.68 ± .05	.69 ± .07		.74 ± .12	.71 ± .14		.68 ± .07	.69 ± .10		83.1

^aEquipped with airborne weather radar.

TABLE VII.- MAXIMUM AIRSPEED DISTRIBUTIONS FROM V-G RECORDS

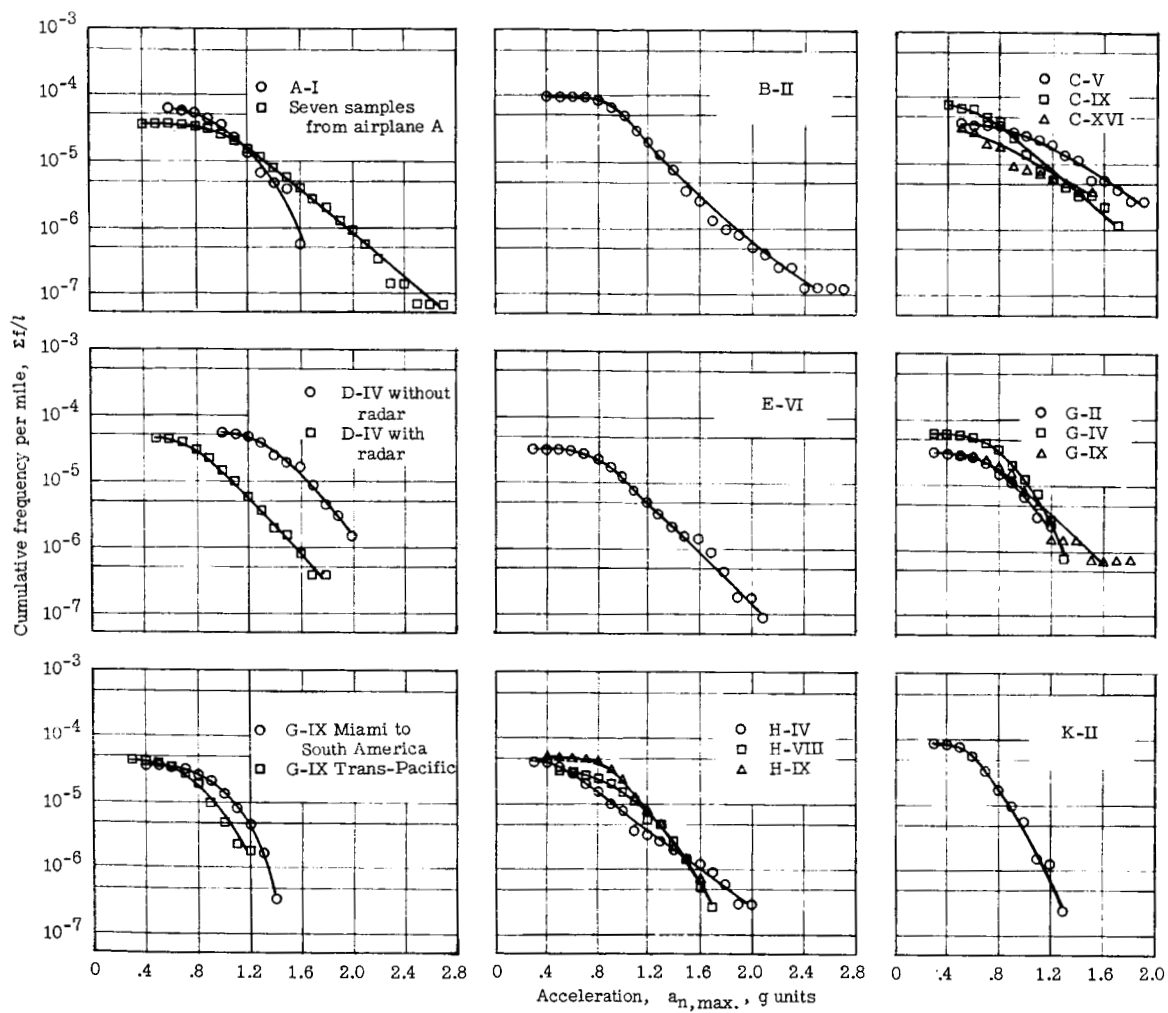
Maximum airspeed, V _{max} , mph	Frequency distribution for operation -																					K-II	
	A-I	A-IV	A-XI	A-XII	A-XIII	A-XIV	A-XV	B-II	C-V	C-IX	C-XVI	D-IV	D-IV (s)	E-VI	G-II	G-IV	G-IX	G-IX (s)	G-XI	H-IV	H-VIII	H-IX	K-II
175 to 180	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
180 to 185	4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
185 to 190	10	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
190 to 195	22	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
195 to 200	10	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
200 to 205	7	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
205 to 210	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
210 to 215	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
215 to 220	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
220 to 225	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
225 to 230	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
230 to 235	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
235 to 240	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
240 to 245	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
245 to 250	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
250 to 255	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
255 to 260	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
260 to 265	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
265 to 270	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
270 to 275	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
275 to 280	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
280 to 285	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
285 to 290	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
290 to 295	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
295 to 300	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
300 to 305	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
305 to 310	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
310 to 315	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
315 to 320	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
320 to 325	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
325 to 330	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
330 to 335	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
335 to 340	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
340 to 345	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
345 to 350	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
350 to 355	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
355 to 360	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
360 to 365	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
365 to 370	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Total	58	10	30	76	19	7	79	388	15	34	13	18	58	133	40	42	57	117	20	74	58	37	166
Flight miles, 11.9x10 ⁶	1.9x10 ⁶	1.7x10 ⁶	1.8x10 ⁶	3.9x10 ⁶	1.9x10 ⁶	0.8x10 ⁶	4.1x10 ⁶	8.0x10 ⁶	0.8x10 ⁶	1.0x10 ⁶	0.8x10 ⁶	0.7x10 ⁶	2.8x10 ⁶	12.0x10 ⁶	2.6x10 ⁶	1.4x10 ⁶	3.1x10 ⁶	5.3x10 ⁶	1.9x10 ⁶	3.6x10 ⁶	4.0x10 ⁶	1.9x10 ⁶	4.1x10 ⁶
V _p at n ₁ max	152	147	151	183	165	156	158	193	194	201	183	209	193	223	173	180	183	176	175	186	213	210	218
V _p /V _C	0.72	0.70	0.71	0.87	0.78	0.74	0.75	0.75	0.69	0.72	0.65	0.64	0.59	0.83	0.78	0.81	0.82	0.79	0.79	0.62	0.71	0.70	0.70
Average flight miles to reach V _{NE} once	6x10 ¹¹	1x10 ¹³	3x10 ⁸	2x10 ⁷	1x10 ⁸	2x10 ¹²	1x10 ¹⁰	3x10 ⁸	2x10 ⁶	2x10 ⁵	5x10 ⁷	1x10 ⁶	1x10 ⁶	3x10 ⁶	3x10 ⁶	2x10 ⁶	2x10 ⁶	2x10 ⁶	2x10 ⁷	2x10 ⁶	2x10 ⁶	6x10 ⁵	2x10 ⁸

*Equipped with airborne weather radar.
†Trans-Pacific operation.



(a) VGH data.

Figure 1.- Frequency with which given values of gust acceleration per mile of flight are exceeded.



(b) V-G data.

Figure 1.- Concluded.

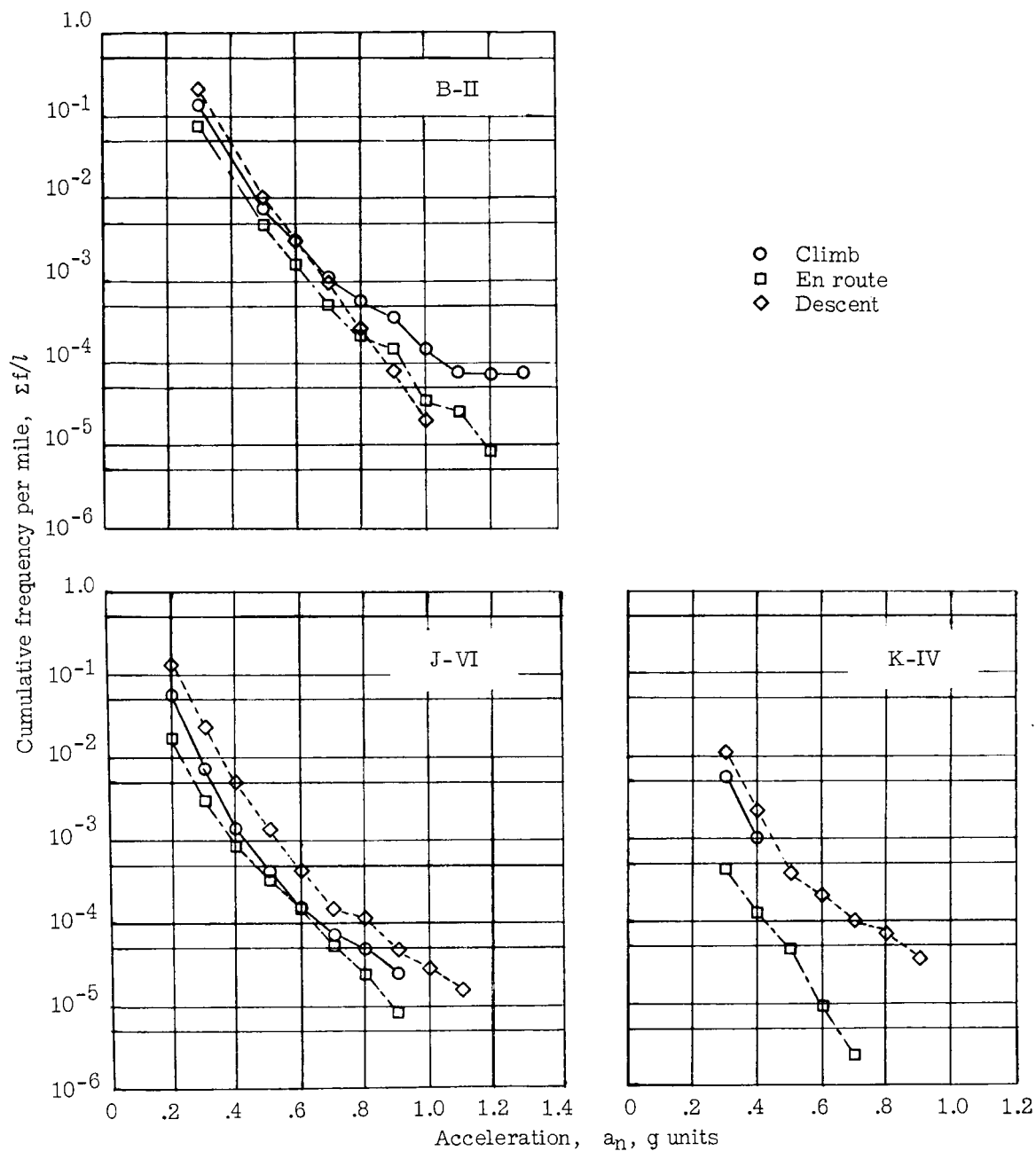


Figure 2.- Frequency with which given values of gust acceleration per mile of flight are exceeded during the climb, en route flight, and descent condition.

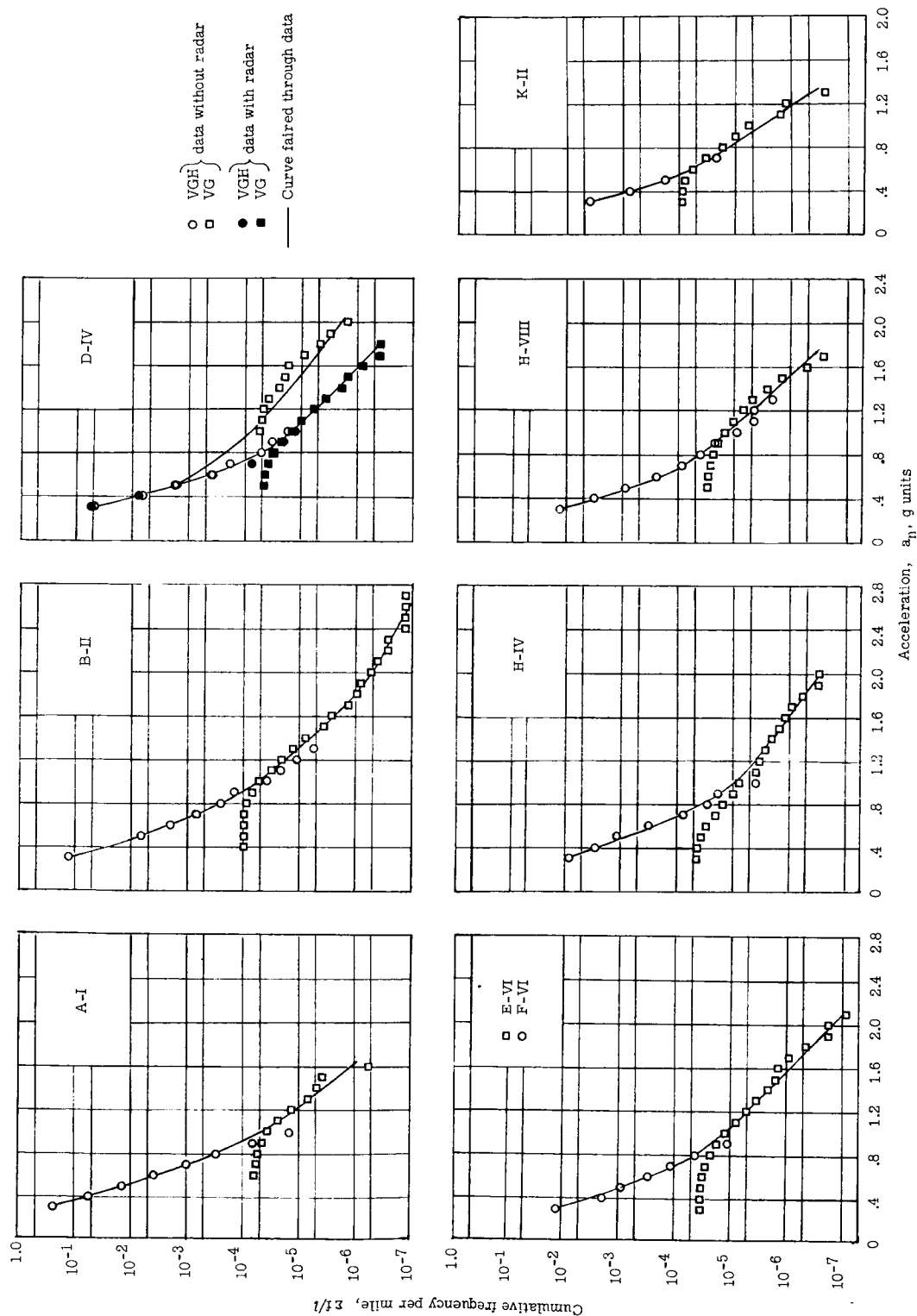


Figure 3.- Frequency with which given values of gust acceleration per mile of flight are exceeded. (VGH and V-G data combined.)

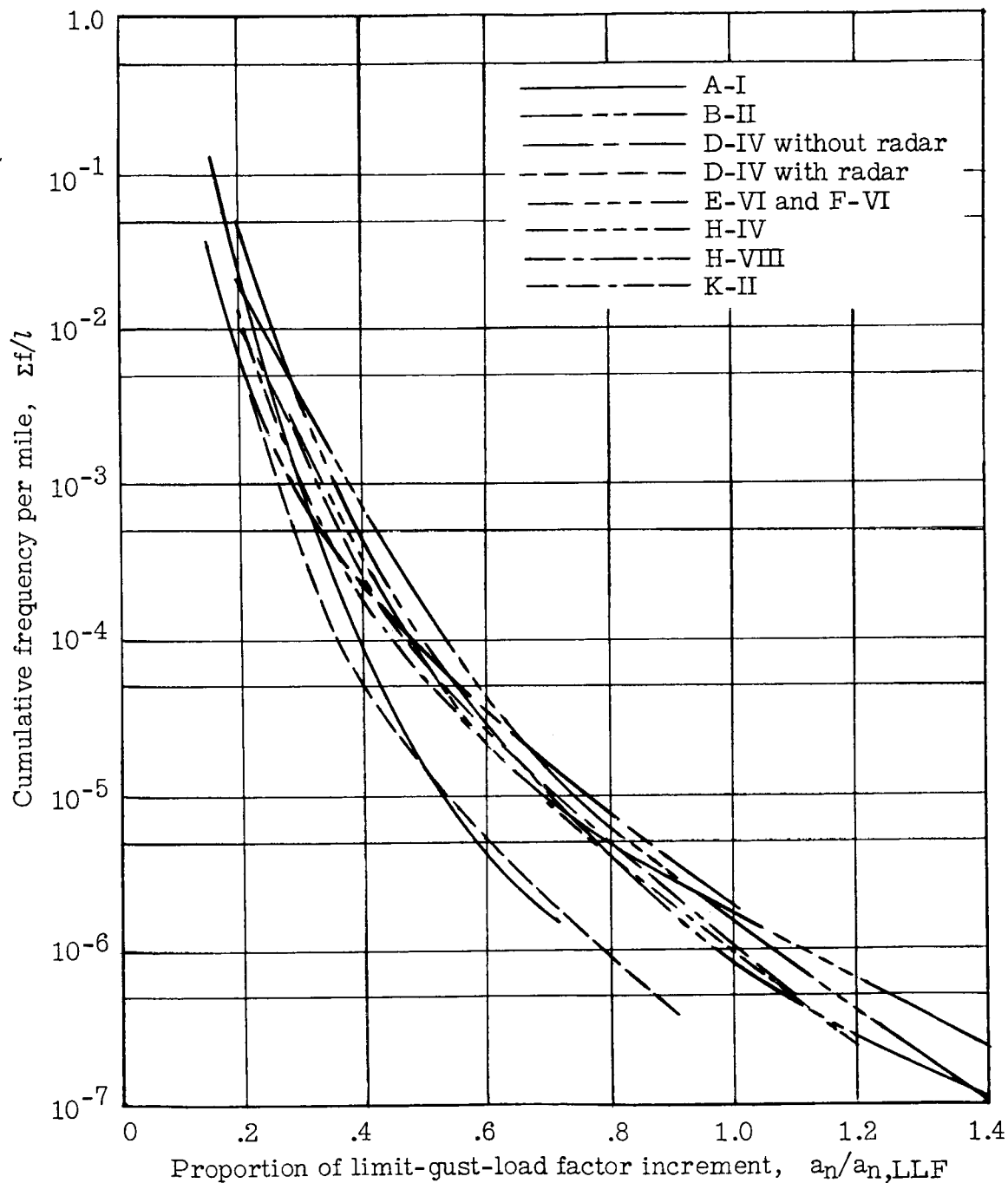


Figure 4.- Comparison of gust-load histories for various operations identified in table I. (VGH and V-G data combined.)

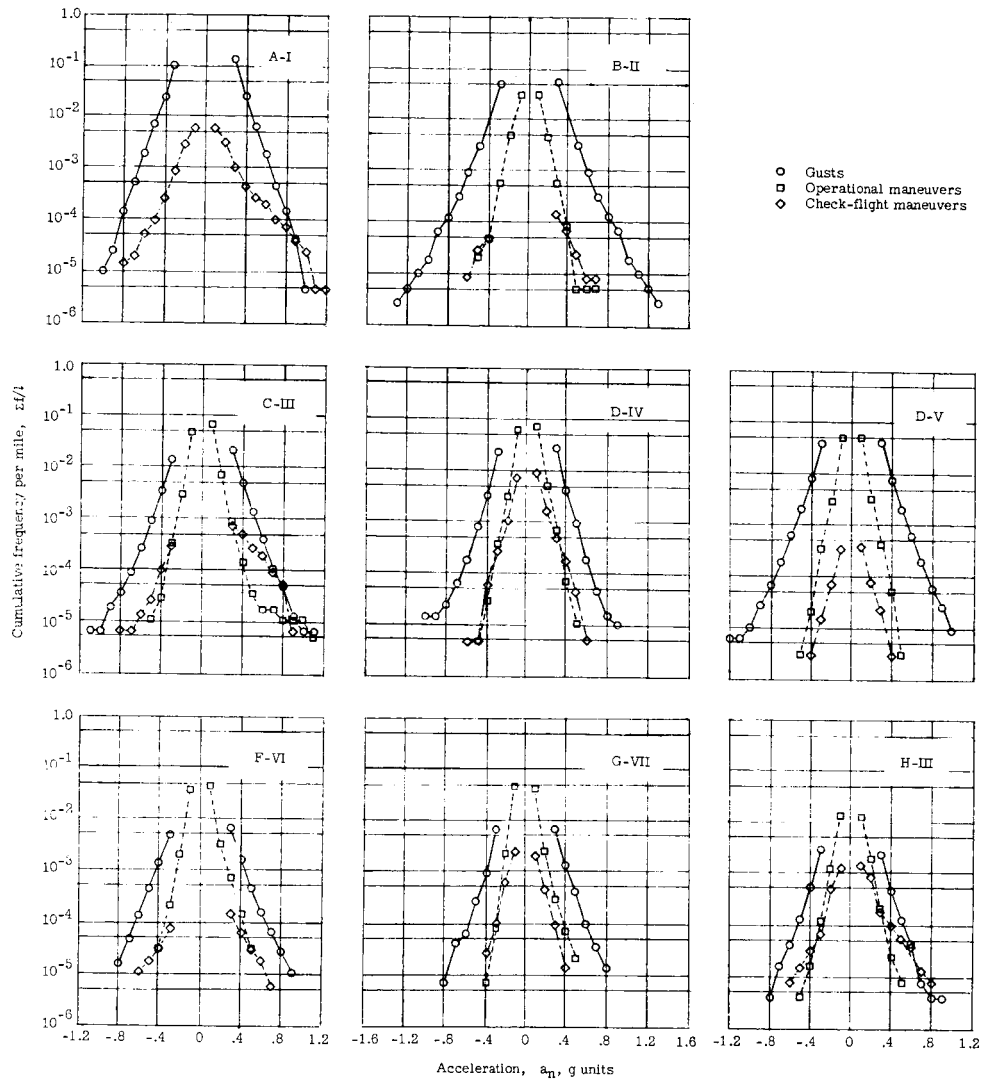


Figure 5.- Comparison of frequencies with which given values of gust and maneuver accelerations per mile of flight are exceeded. (VGH data.)

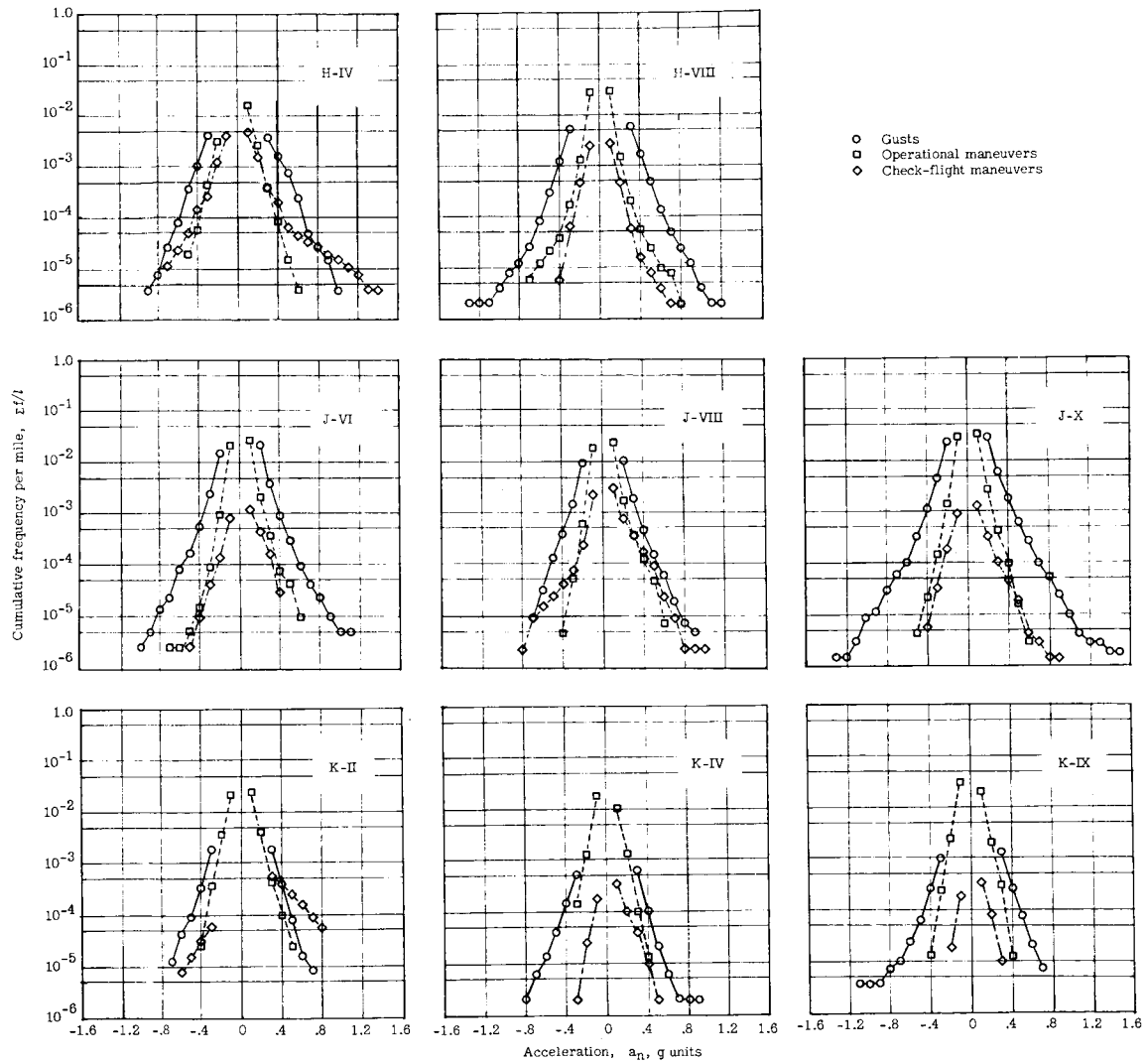
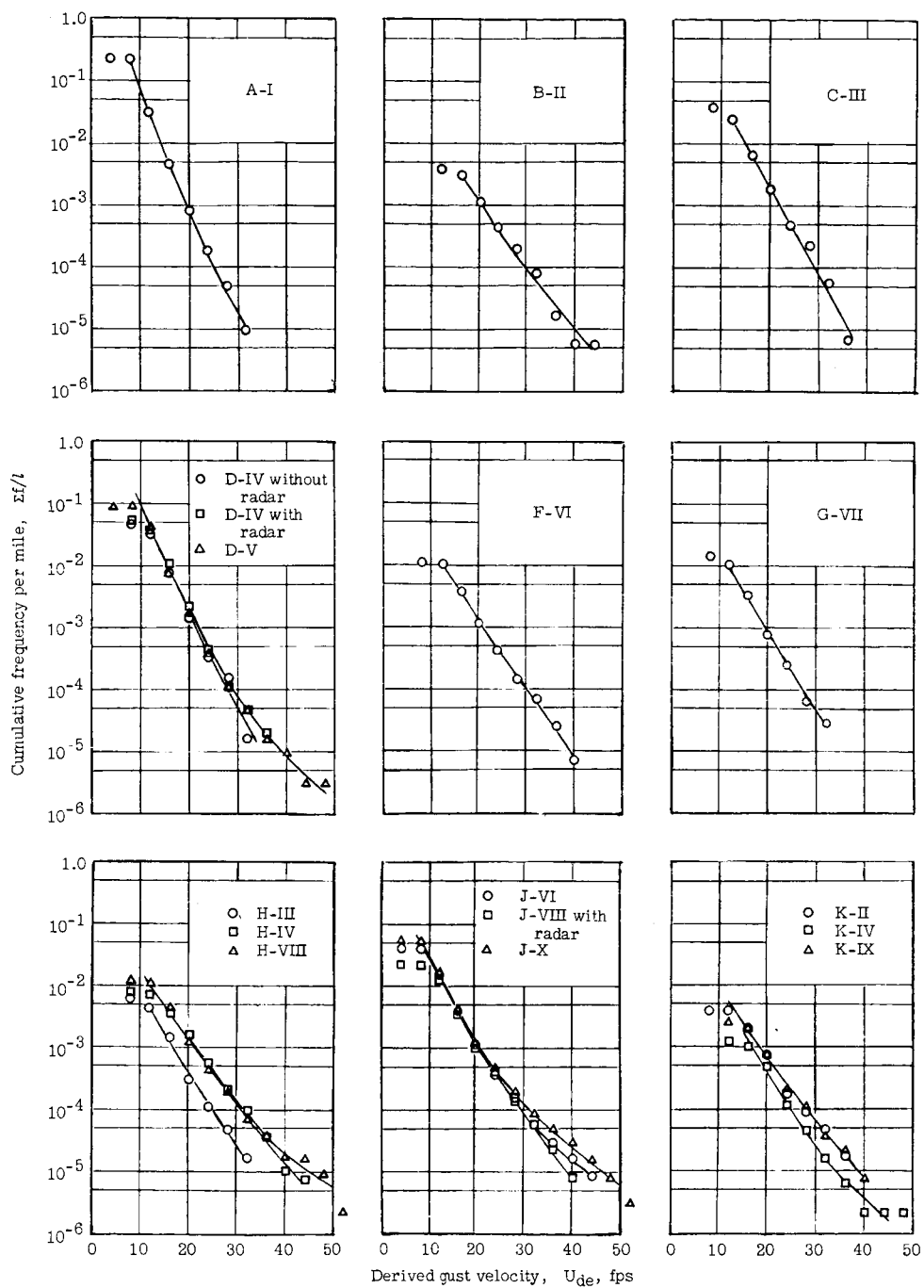
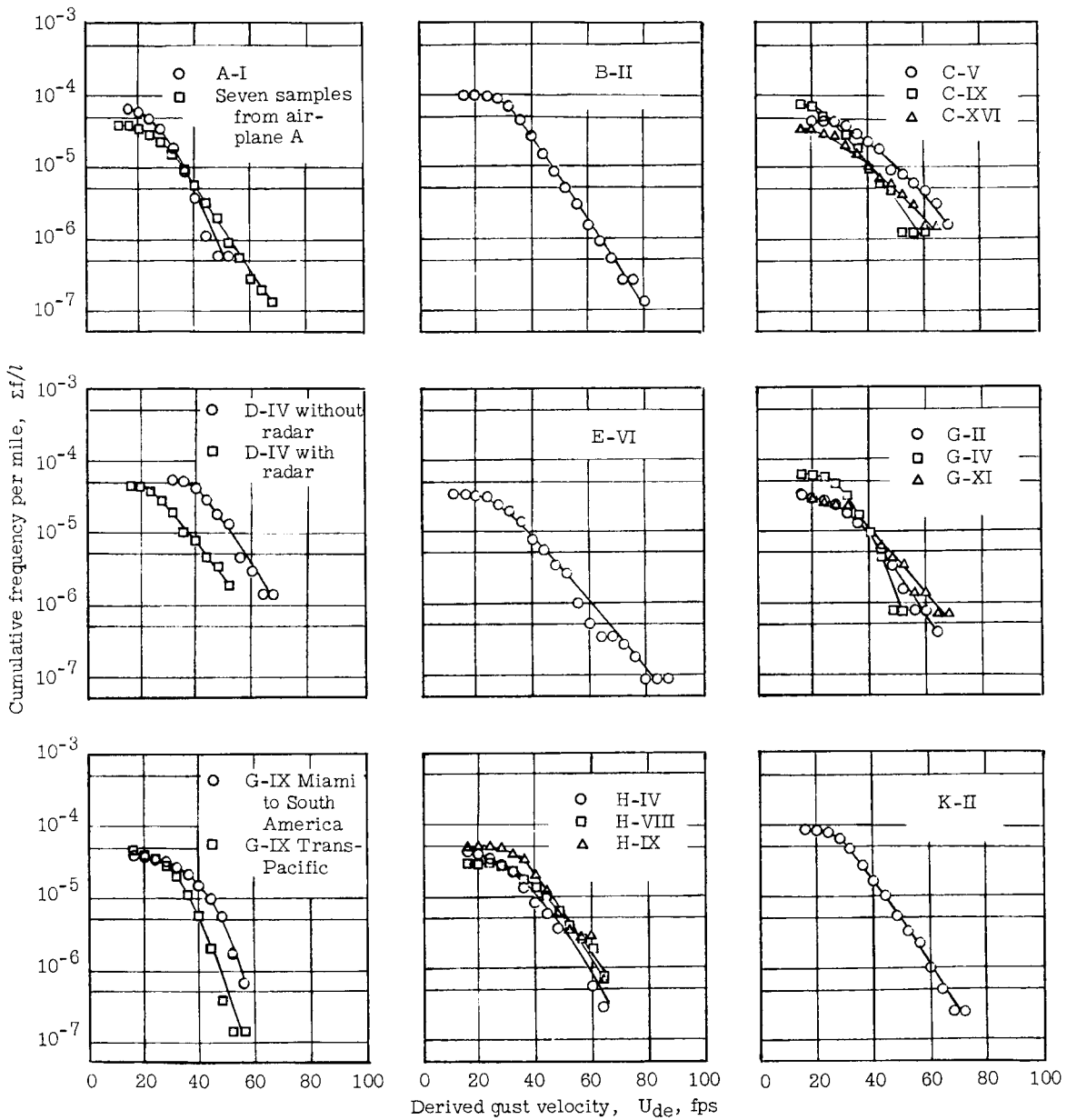


Figure 5.- Concluded.



(a) VGH data.

Figure 6.- Frequency with which given values of gust velocity per mile of flight are exceeded.



(b) V-G data.

Figure 6.- Concluded.

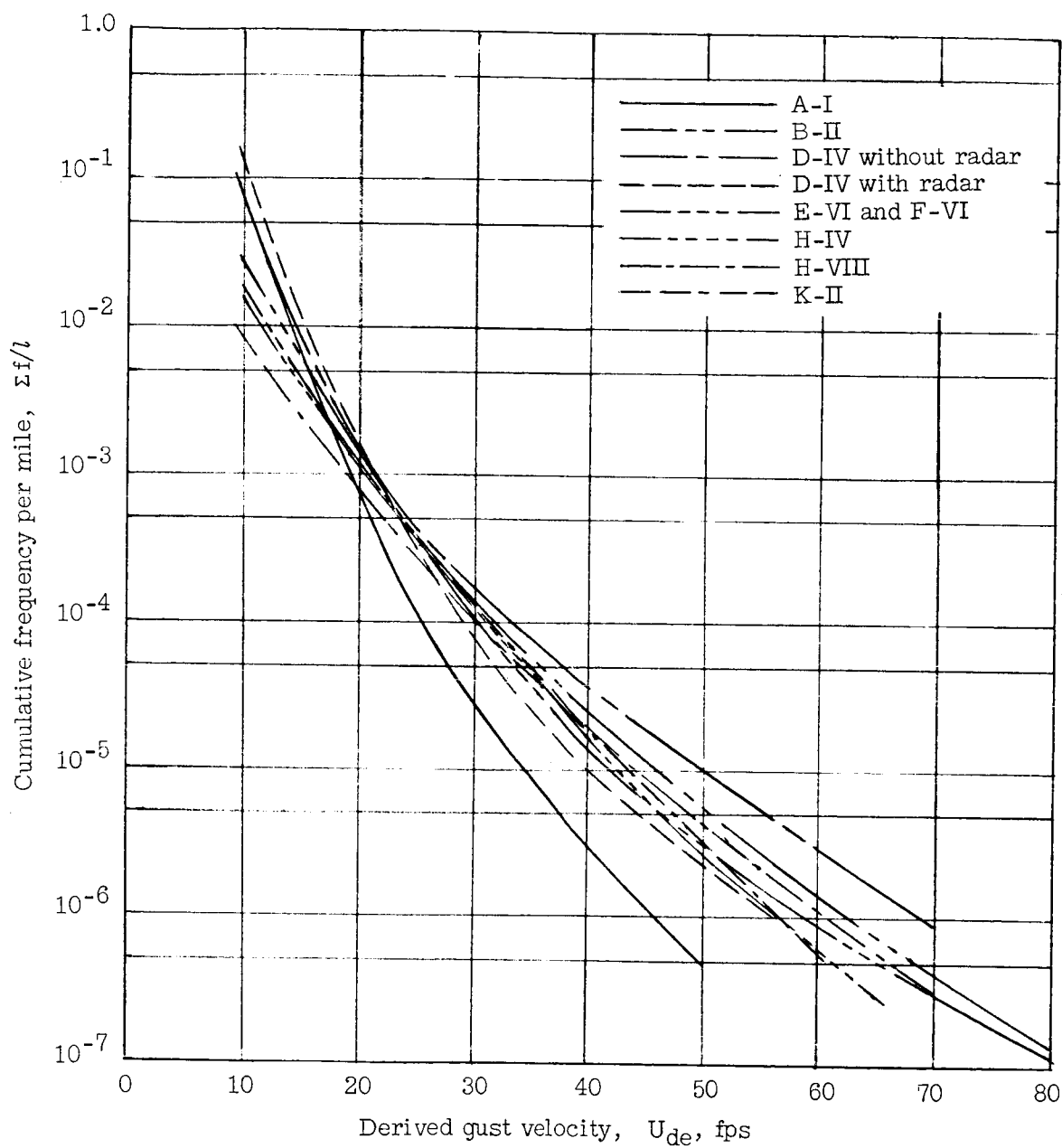


Figure 7.- Comparison of derived gust-velocity histories. (VGH and V-G data combined.)

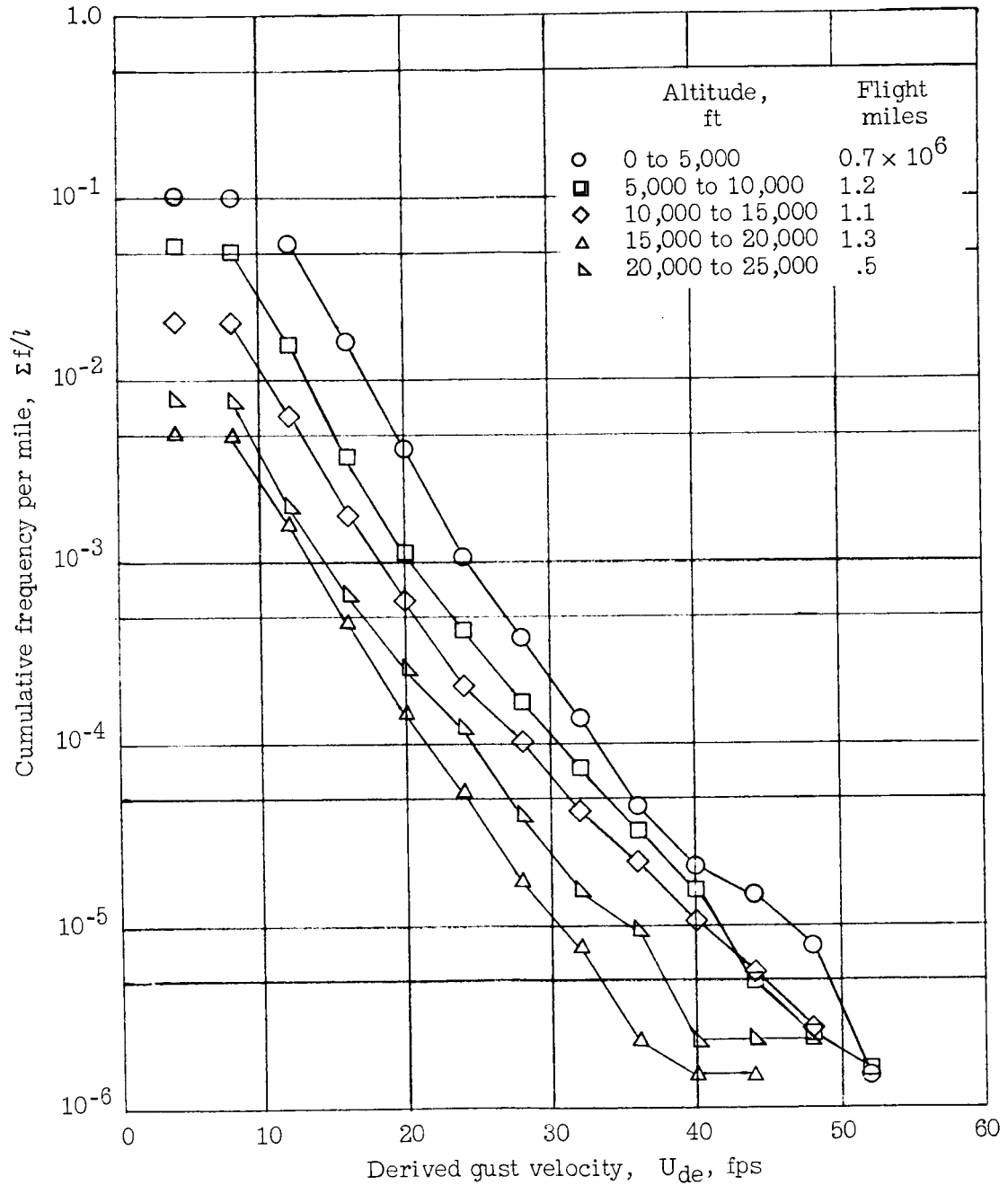
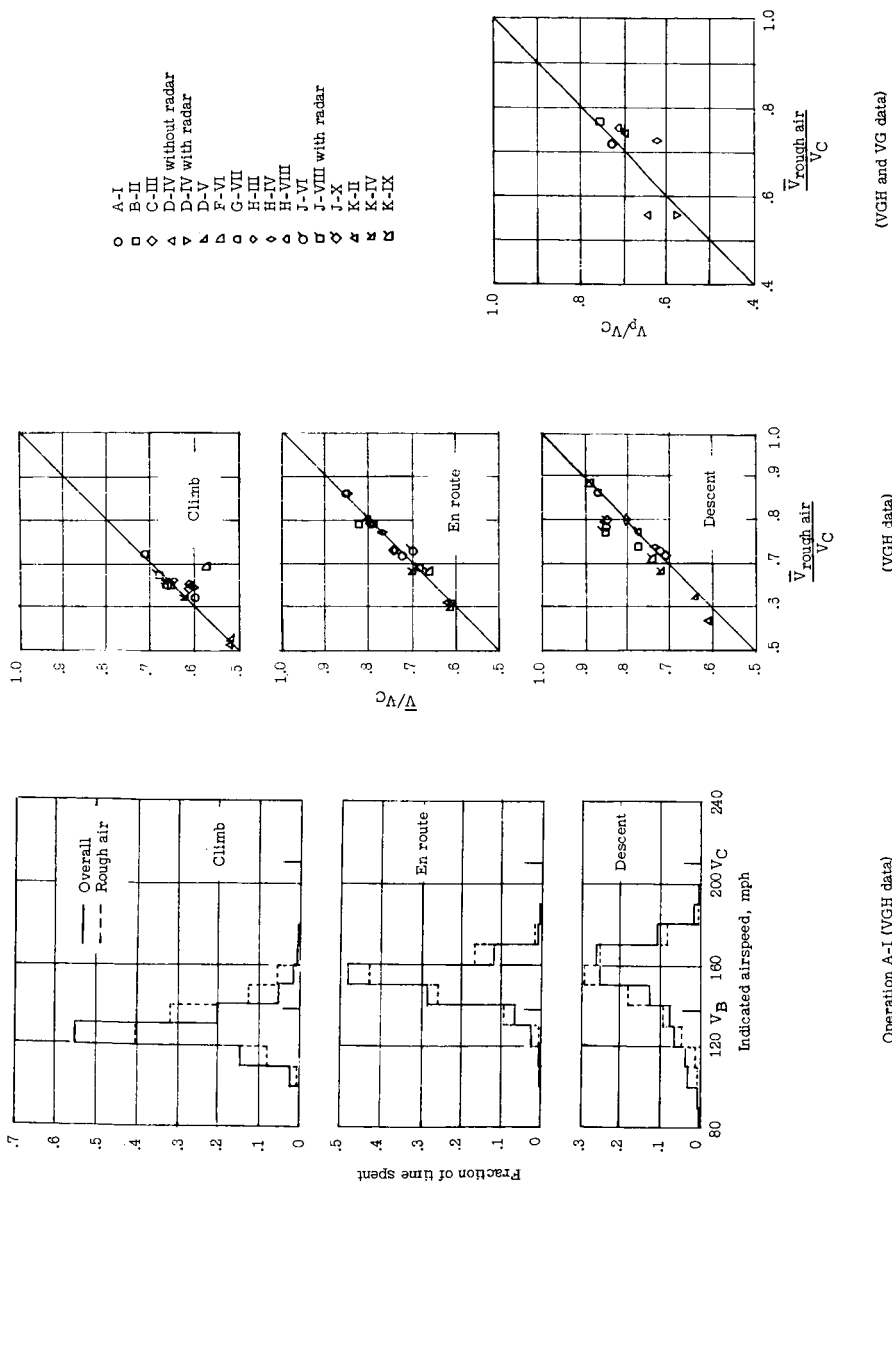


Figure 8.- Frequency of exceeding given values of derived gust velocity per mile of flight with pressure altitude. (VGH data.)



(a) Comparison of distributions of overall airspeed with distributions of airspeed in rough air by flight condition.

(b) Comparison of the average airspeed in rough air with the average overall airspeed.

(c) Comparison of the most probable speed for maximum acceleration occurrence (V-G data) with the average airspeed in rough air (VGH data).

Figure 9.- Comparison of operational airspeeds for different flight conditions.

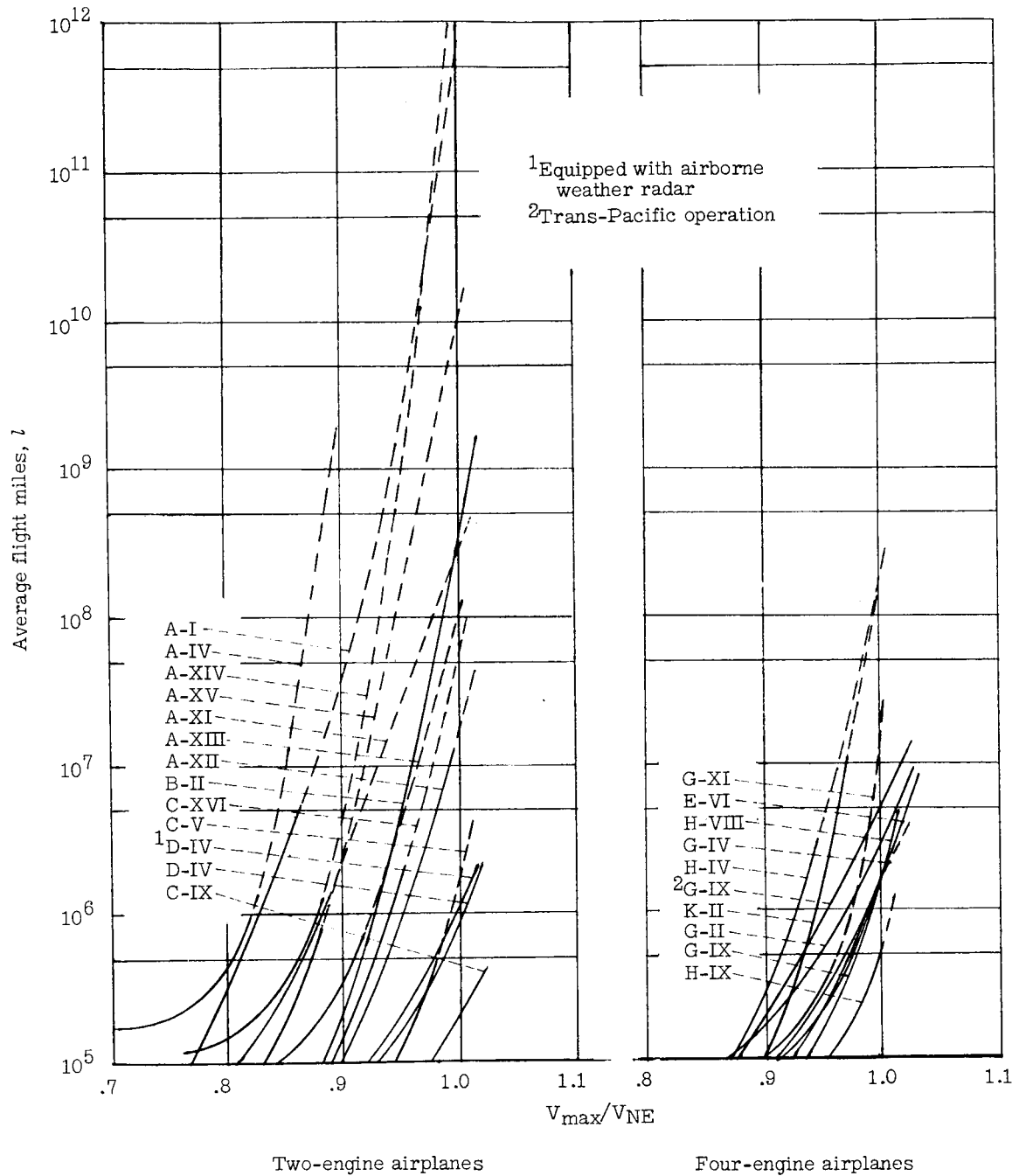


Figure 10.- Average flight miles for maximum indicated airspeed to exceed a given value. V-G data. (Dashed part of curves are extrapolated.)

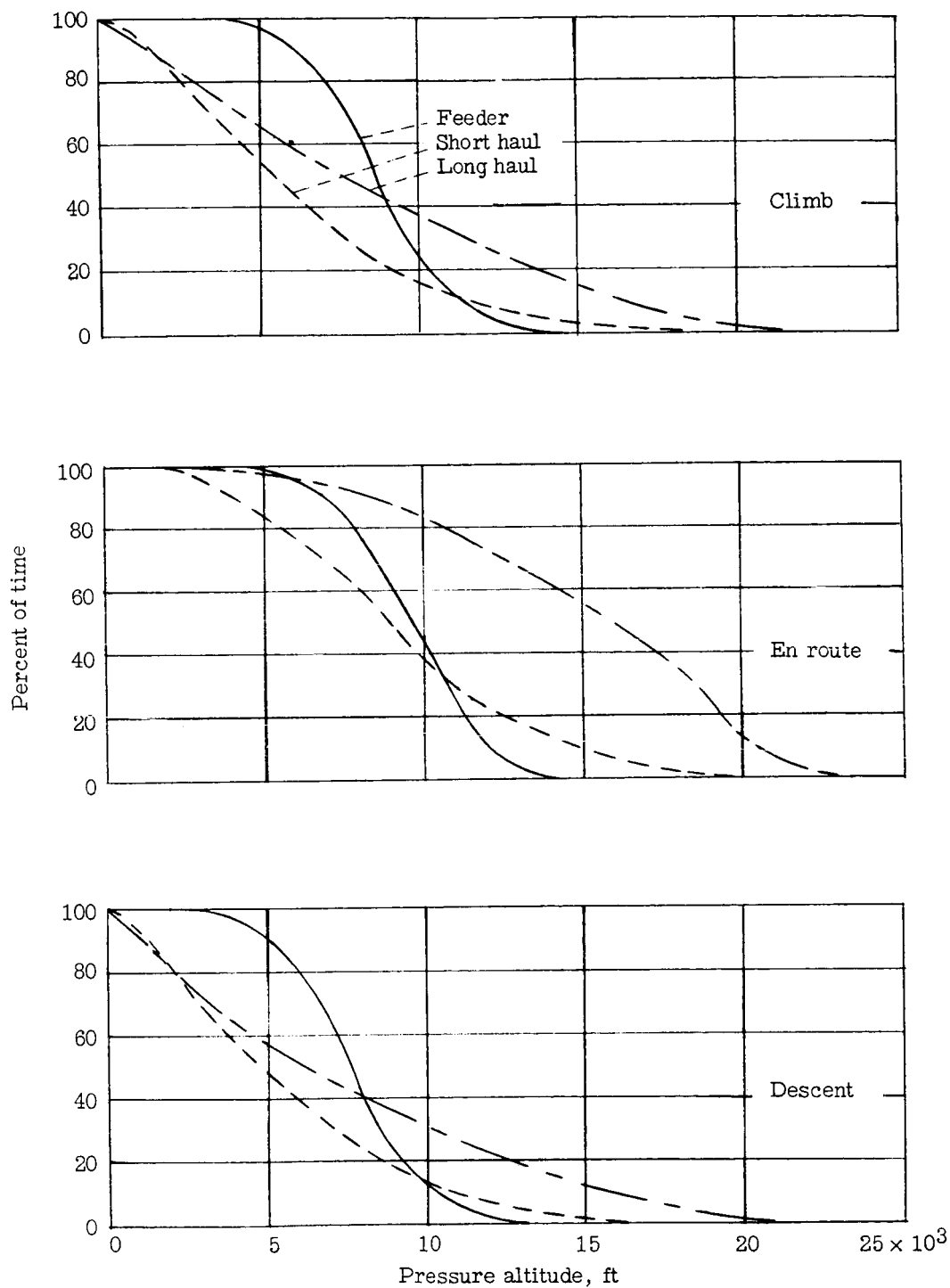


Figure 11.- Percentage of time spent above given altitudes during the climb, en route, and descent flight conditions. (VGH data.)